DESIGN AND IMPLEMENTATION OF AN AUTONOMOUS VEHICLE FOR WASTE MATERIAL COLLECTION AND FIRE DETECTION

Orkun AYDIN[1], Ersin MOLLA[2], Ferhat KARADAĞ[3], Burak GÜZELTEPE[4], Hakkı Ulaş ÜNAL[5*], Ömer Nezih GEREK[6]

[1] Eskişehir Teknik Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Eskişehir
ORCID No: 0000-0001-8458-8910
[2] Eskişehir Teknik Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Eskişehir
ORCID No: 0000-0003-0431-5862
[3] Eskişehir Teknik Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Eskişehir
ORCID No: 0000-0001-5197-0419
[4] Eskişehir Teknik Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Eskişehir
ORCID No: 0000-0003-3609-200X
[5] Eskişehir Teknik Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Eskişehir
ORCID No: 0000-0001-8979-4625
[6] Eskişehir Teknik Üniversitesi, Mühendislik Fakültesi, Elektrik-Elektronik Mühendisliği Bölümü, Eskişehir
ORCID No: 0000-0001-8183-1356

Keywords

Autonomous vehicle, real-time object detection, YOLO.

Abstract

Autonomous vehicles are becoming increasingly popular in a variety of applications, including waste collection and fire detection. In this work, we present the design and implementation of an autonomous vehicle for these tasks in urban environments. The vehicle is equipped with sensors and control algorithms to navigate, detect and collect plastic bottle wastes, and detect fires in real-time. The system uses an off-the-shelf, small-sized, battery-operated vehicle, a simple conveyor belt, and a vision-based, computerized system. Machine learning (ML-) based vision tasks are implemented to direct the vehicle to waste locations and initiate the waste removal process. A fire detection and alarm system are also incorporated, using a camera and machine learning algorithms to detect flames automatically. The vehicle was tested in a simulated urban environment, and the results demonstrate its effectiveness in waste material collection and fire detection. The proposed system has the potential to improve the efficiency and safety of such tasks in urban areas.

ÇÖP MATERYALİ TOPLAMA VE YANGIN TESPİTİ İÇİN BİR OTONOM ARAÇ TASARIMI VE GERÇEKLEŞTİRİLMESİ

Anahtar Kelimeler

Otonom araçlar, gerçek-zamanda obje tespiti, YOLO.

Öz

Otonom araçların, çöp toplama ve yangın tespitini de içeren çok çeşitli uygulamalarda popülerliği artmaktadır. Bu çalışmada, kentsel alanlarda kullanılmak üzere bu uygulamalar için bir otonom araç tasarımı ve gerçeklemesi sunulacaktır. Araç, üzerinde bulunan algılayıcılar ve tasarlanan kontrol algoritmaları ile gerçek zamanda etrafını tarayıp plastik çöp şişelerini tespit edip toplayacak ve yangın tespiti yapacaktır. Sistem, özel olarak tasarlanmış ve akü ile çalışabilen küçük boyutlu bir araba, basit bir konveyör bant, görüntü tabanlı küçük bir bilgisayar sistemi kullanmaktadır. Aracı, çöplerin olduğu yere yönlendirip çöpü ayırma işlemini başlatması için Makine öğrenimi (ML-) tabanlı görüntü algoritmaları uygulanmıştır. Bir kamera ve alevleri otomatik tespit edecek makine öğrenme algoritmaları ile, yangın tespiti ve alarm sistemi de sisteme entegre edilmiştir. Araç, kentsel ortama benzetilmiş bir alanda test edilmiş ve edilen sonuçlar çöp materyali toplama ve yangın tespitinde ne kadar etkili olduğu göstermiştir. Önerilen sistem, kentsel alanlarda daha verimli ve güvenli olacak şekilde geliştirilebilir potansiyeli vardır.

Araştırma Makalesi		Research Article	
Başvuru Tarihi	: 13.01.2023	Submission Date	: 13.01.2023
Kabul Tarihi	: 14.08.2023	Accepted Date	: 14.08.2023

* Sorumlu yazar: huunal@eskisehir.edu.tr
https://doi.org/10.31796/ogummf.1233759

Bu eser, Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/) hükümlerine göre açık erişimli bir makaledir.
This is an open access article under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/).

1. INTRODUCTION

Plastic is a widely used and essential material in manufacturing and packaging, with applications ranging from medical devices to renewable energy technologies (Giacovelli, 2018; Andrady and Neal, 2009). However, the rapid growth in global plastic production has also led to a significant increase in plastic waste, with humans currently producing approximately 400 million tons of plastic per year, half of which is single-use plastic such as packaging and bottles. This plastic pollution has become a major threat to life on earth, with only 10% of plastic products being recycled (Padervand, Lichtfouse, Robert and Wang, 2020). Plastics are not biodegradable and break down into smaller particles called microplastics, which are harmful to all types of land and aquatic life, including humans (Azoulay et al., 2019).

Public parks and picnic areas are often impacted by plastic waste, as visitors carelessly dispose of trash and leave these areas polluted. Despite laws aimed at keeping these areas clean, enforcement is often insufficient. In addition, recreational areas are usually pastoral places with trees, bushes, and wood. They are occasionally left empty, or sometimes, there are only inexperienced or unattended young. The carelessly disposed water bottles sometimes cause optical heating and generate fire.

In this work, an autonomous vehicle design to achieve the following objectives is considered:

- Detection and collection of plastic bottles using machine vision,
- Navigation towards waste using optimized robotic routing,
- Collection of waste using a conveyor,
- Transportation of waste to a central location,
- Automatic detection of flames using machine learning algorithms.

The vehicle is designed with the capability of highly skilled maneuvers and mobility in regions with planted trees and bushes. Moreover, by the proposed algorithm and its choice of vehicle size, it can locate the garbage items even in occluded corners within the whole scanning area. Since the area scanning algorithm is exhaustive, the vehicle is very likely to detect and alarm in case of fire within a very short time.

2. Literature Review

Autonomous vehicles have the potential to address this problem by reducing unnecessary costs, saving time, and performing tasks in potentially hazardous environments without human intervention (Wall, Bennett and Eis, 2002; Anderson et al., 2016). Autonomous vehicles have been used for a variety of purposes, including agriculture (Nielsen, Andersen, Pedersen, Bak and Nielsen, 2002), surveillance missions (Naranjo et al., 2016), logistics and shipping (Yu and Lam, 2018), and garbage collection (Arai, Miyagusuku and Ozaki, 2021).

There have been studies on autonomous garbage collection vehicles, and some companies have even developed commercial autonomous garbage collection vehicles (Evan, 2018). In addition to these works, there exist numerous works on autonomous vehicle design for garbage collection (Jha et al., 2019; Mayorga et al., 2019; Banu and Florence, 2022; Diyva and Latha, 2021; Pyo et al. 2022; Ying and Zhang, 2018; Kulshreshtha et al. 2022; Assis, Biju, Alisha, Dhanadas, Kuria, 2012; Bai, Lian, Liu, Wang and Liu, 2018; Huang et al., 2022). However, many of these vehicles are large and require GPS localization to collect waste in specific locations, on the other hand, there exist only a few works considering fire detection. In (Pyo et al., 2022), an autonomous vehicle is designed to achieve garbage collection using a camera, radar, and lidar. In addition, recognition, lane recognition, route planning, vehicle manipulation, and abnormal situation detection were considered in that work. In (Bai, Lian, Liu, Wang, and Liu, 2018), deep neuronal networks are used for object detection. However, different than our work, object detection algorithms in that work are not real-time. Recently, an autonomous vehicle design for certain garbage detection is given in (Jha et al. 2019), which uses infrared and ultrasonic sensors to detect garbage. However, the approach in that work does not specify the nature of the garbage. Besides, the proposed robot is not low-cost.

Depending on the composition of disposed chemicals, a fire could even ignite quite randomly. Therefore, automatic and vision-based detection of fire or flames is also a valuable operation in related places (Park et al., 2019). Since garbage-collecting vehicles already contain a camera system with computers, the addition of an extra automatic fire detection algorithm is a common practice (Savla, Parab, Kekre, Gala and Narvekar, 2020).

This work presents the design approaches and implementation details of an autonomous vehicle for waste material collection in recreational areas, with a focus on optimizing the size and location independence of the system.

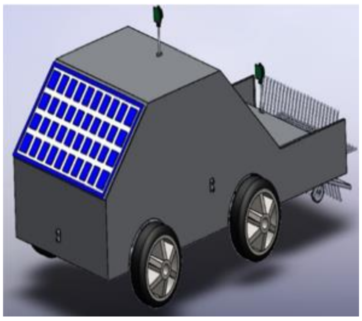
In the remainder of this paper, Section 3 starts by describing the hardware design, followed by the software design, and finally, continuing with the experimental setup and results. Conclusions and possible use cases are discussed in Section 4.

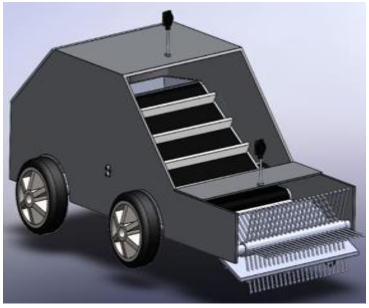
3. METHOD

3.1 Mechanical Design

The designed vehicle is required to detect, navigate to, and collect plastic bottles of certain sizes and move them into its container. A conveyor system is designed to carry these bottles into the container. In order to locate the bottles over the conveyor, four nylon strip brushes, each with a width equal to that of the vehicle, are designed and mounted on a plastic cylinder to collect average-sized plastic bottles. A SOLIDWORKS™ illustration of this prototype is shown in Fig.1.

This prototype was designed by taking the wheel and shaft system of a battery-operated child vehicle, which is shown in Fig. 2(a), as a reference. In order to let the vehicle reach to mode tricky corners and increase its mobility, the length, width, and height of the vehicle are taken as 100 cm, 60 cm, and 50 cm, respectively. It should be noted that carrying the plastic bottle to a conveyor is not a trivial task. It is observed that the brushes may occasionally be too intense for very light bottles for smooth and accurate collection. In order to overcome this issue, the brushes are covered by lightweight material, as shown in Fig 2(b). In order for the vehicle to perform its cleaning function on sloping terrain and in environments with obstacles such as stones, three wheels are considered to be installed under the conveyor system.


(a)


(b)

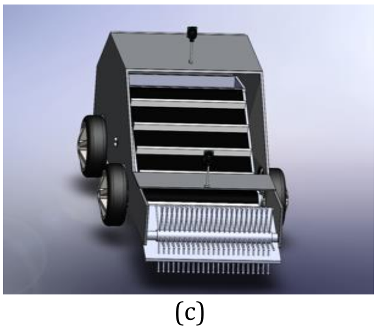
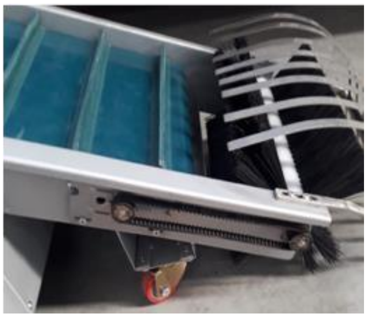

(c)

Figure 1. Different views of the solid model: (a) back view; (b) side view; (c) front view.

Once the electronic circuit diagram of the vehicle was prepared, the necessary assembly and support designs were made to fix the parts, such as the driver, engines, sensors, and cables in the vehicle. The prepared support parts were manufactured with a 3D printer and mounted on the vehicle according to the designed mounting patterns. The limiting factor in determining the slope and length of the conveyor system was that the waste should be conveyed to the storage without rolling or drifting. Finally, the prototype was obtained, as shown in Fig 2(c).


(a)


(b)


(c)

Figure 2. Steps to real model: (a) A battery-operated toy vehicle; (b) Conveyor-Brush system; (c) Prototype.

3.2 Hardware

The hardware requirements are determined by assuming that the vehicle scanning area must leave no gaps within its operational range. In order to collect bottles and move them to the container by the conveyor, respectively, 12 V 500 rpm and 12 V 30 rpm geared DC motors are used. The underlying reason to choose DC motor having high speed and torque stems from the fact that the weight of bottles is light, hence, it may be difficult to transmit the captured bottle to the conveyor. In order to provide the required power for driving dc motors and for other parts, which are explained in the sequel, 12V – 24Ah gel batteries have been used. The batteries have acid gel density, which significantly increases the discharge and vibration tolerance of the battery. The speed of the dc motors is controlled by dc motor control modules, which are the relay module and L298N motor driver controller. By taking into account the weight of the conveyor and the batteries, a third high torque 60 kg-cm DC servo motor is used to turn the vehicle in the desired direction. The power of the motor was delivered by a 12V-24Ah gel battery, and its control is done over PCA 9685 servo driver unit. The direction, hence, control of the vehicle, is determined by carrying out the proposed robotic navigation algorithms on the NVIDIA Jetson AGX Xavier processor module. This module is equipped with Raspberry Pi 8 Mp Original Camera Module, which has 8Mp Sony IMX219 image sensor with a fixed focus lens. The camera is used to object detection, and a schematic representation of the vehicle is as shown in Figure 3.

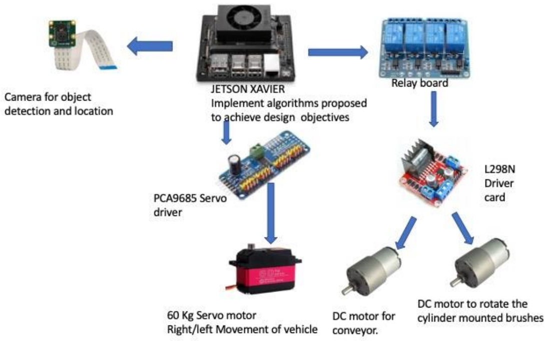


Figure 3. The schematic representation of control unit

In addition, via the implemented algorithm and DC motor control card, the speed of the vehicle is adjusted (Aydın, Molla, Karadağ and Güzeltepe, 2021).

3.3 Software

The primary purpose of the project is the detection and collection of plastic bottles, with an additional feature of flame detection for quick detection of tree fires. In order to achieve these tasks, one way is to use object detection from images. The developed object detection algorithms perform object classification and localization inside the image (Zhao et al., 2019). Recent developments in deep learning methods have yielded new, fast and accurate object detection techniques when compared to conventional image processing methods (Zhao et al., 2019; Zou et al., 2019; Tivelius, 2021). These recent object detectors can be categorized into two major groups according to the number of flow networks: (1) a one-stage detector, which uses only one convolutional network, and (2) a two-stage detector, which is built using two separate networks (Zou et al., 2019). One-stage detectors are, naturally, very fast; however, they are less accurate than two-stage detectors (Zou et al., 2019). Nevertheless, by accurate training and parametric fine-tuning, recent one-stage detectors have started to outperform two-stage detectors on certain tasks (Zou et al., 2019). One such successful one-stage detector is YOLO (Redmon et al., 2016). This detector divides the image into a grid of smaller cells, and each convolutional layer assigns a probability that a cell contains a particular object. Next, the neighboring cells with a high probability of containing the desired object are combined to re-form into larger boxes. The final large boxes that contain the detected objects are tagged and labeled. Since YOLO is able to process the entire image, it performs well at investigating images with more than one object (Redmon et al., 2016).

Figure 4. Object detection algorithm training steps

The process steps given in Fig. 4 were applied to achieve the main goals of the work. Experiments were done by training hundreds of acquired and downloaded images that were fed into the training algorithm. The images were selected to contain various bottle shapes, sizes, and surrounding environments. In addition, the pictures used in the advertising shots of plastic bottles with many different types and designs are also included in our data. A further dataset that contains further thousands of various flame and fire images was used for the training regarding flame detection. The specific version of YOLOv5 with the Darknet Model Library was used. The architecture was already pre-trained with the MS COCO dataset that detects about 100 distinct and well-known objects. On top of the pre-training, we obtained about 800 photos taken in different environments from dissimilar angles for fine-tuning. The photos were gathered from regions with various backgrounds. In addition, several pictures used in various advertisements of several products with plastic bottles were also included in our data. For the flame detection part, an online dataset consisting of approximately 1000 images was used for training with flame images. It must be noted that "flame" is not a compact object, and it can appear in a wide variety of places. Besides, it is not a defined object in the MS COCO pre-training dataset.

Therefore, we have tried to utilize as many flame images as possible in the training process.

The particular implementation (roboflow) of the software environment, called Spyder, requires the image size to be 416x416. Despite having hundreds of training data, the data set was enriched through classical data augmentation techniques such as varying brightness, saturation, shifts, and rotations. The resulting data were divided into two groups: 90% for the training and 10% for testing, corresponding to the famous ten-fold cross-validation. As an economic platform, Google Colab was used. The roboflow site was configured as a custom dataset with YOLOv5. In Colab, the training took about 1.5 hours for 100 epochs. It was estimated that the training could take 7-8 hours, if done with older YOLO versions, such as YOLOv4. The weight and configuration files obtained at the end of the training were made ready for use in Spyder. Since the resulting images contain rectangular boxes (i.e., blobs), certain post processes were applied to convert the resulting test images into useful commands for the automated guided vehicle's computer. The first process starts by eliminating detections of unnecessary objects. Then, an array of detected desired objects together with their coordinates were converted to physical coordinates for the motion of the vehicle, starting the movement according to the largest bottle object, as it is assumed that the larger bottle is expected to be the nearest one to the vehicle.

4. Results & Discussion

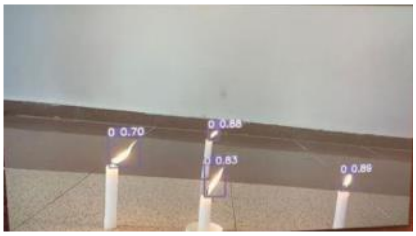
In this study, the object detection confidence intervals were set according to the detection probability figures that were provided by the YOLO object recognition algorithm. If the confidence score coming from YOLO is obtained to be greater than the determined confidence threshold, the object is tagged together with its bounding box, whose coordinates also come from YOLO. Together with the available computational hardware, the frame rate for these operations was obtained to be well above 20 fps.

Since the vehicle inspects the whole area, the fire detection process is just a side property of the system. While wandering, once a flame is detected, the vehicle stops and sends an alarm signal to the server computer, which is forwarded to city authorities. It must be noted that the proposed vehicle is not equipped with any fire extinguishing tools. The achieved flame detection probabilities using real-life cases are illustrated in Fig. 4.

As seen in Fig. 5, flame regions are usually detected with an object recognition probability of above 0.70, depending on the distance from the camera. At a faraway distance, where the camera may have difficulty in detecting, flame detection can still be done even if the detection confidence score drops to 0.55.

The view that triggers and activates the vehicle towards a specific location is the detection of plastic bottles. Fig. 6 shows the detection probabilities of plastic bottles in simple environments. A clean sight of an intact bottle has a confidence score of approximately 0.85, while a compressed bottle has a higher confidence score of 0.90 behind a relatively smooth background. Views from parks with complicated bush backgrounds indicate that these bottles could still be detected with confidences above 0.80. We assess that a confidence interval threshold of 0.5 is sufficient for detecting all the plastic bottles with close to zero false detection rates, even at complicated backgrounds.

(a)



(b)

Figure 5. Flame Detection. (a) The distance between flames and vehicle; (b) The accuracy rates in flame detection.

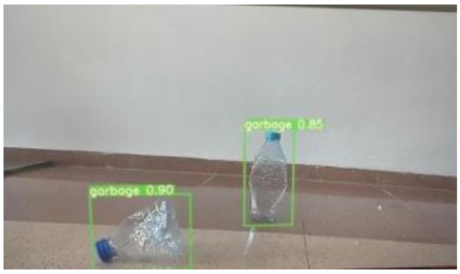


Figure 6. Accuracy rates for bottle detection.

After fine-tuning the recognition confidence thresholds, once a waste object is detected, the vehicle moves along to direction of the waste by centralizing the detected object region within the angle of camera view, using dc motor control cards. Using simple controllers and the conveyor, the waste bottles are collected by rotating brushes whenever the vehicle is sufficiently close to them. A video of the actual prototype device can be reached from the following link:

https://www.dropbox.com/s/med94diny2rqmtr/IMG_0029.MP4?dl=0

The YOLO algorithm locates the object inside the image frame by a bounding box. The robot simply aims to move and navigate in a way that the center of the object's bounding box is vertically aligned with the center line of the vehicle mechanism. It is an adaptive process as the vehicle moves. Therefore, the vehicle does not need to coordinate-wise locate the object. As the vehicle moves "towards" the center of the object, at one point, the object is mechanically removed, and the camera confirms that the object removal process is complete. Consequently, the control structure is a minimum-cost open-loop control, and a full self-location or object location is not necessary.

5. Conclusions

This work presents an autonomous solution for the real-world problem of plastic bottle collection and fire detection in recreational areas. The proposed solution involves the design and implementation of an autonomous vehicle that uses electro-mechanical components and software to navigate, detect, and collect plastic bottles and detect flames. The vehicle uses computer vision techniques and control algorithms to scan the environment, and approach detected waste bottles. The prototype demonstrates the mechanical and algorithmic feasibility of using an autonomous vehicle for these tasks and has potential for commercial application, as the algorithms can be extended to collect other types of pollutants or objects based on size, type, and properties.

This work can be considered as a guide to designing an autonomous vehicle, which aims to detect certain objects in real-time and carry them to somewhere while avoiding obstacles. As a future work, path-planning algorithms and robust controller design techniques should be considered to minimize some cost functions and also renewable energy sources should be discussed.

Acknowledgement

This work was performed as a graduation project under courses EEM 413 (P) and EEM 414 (P) in the Dept. of Electrical and Electronics Eng. at Eskisehir Technical University. It was supported by Eskisehir Technical University Scientific Research Projects Commission under grant no: 21LTP040. It was also supported by TUBITAK 2209/A with grant no 1919B012004030. The authors would like to thank DEPARES for the mechanical part and Hisarlar Makine Inc. for providing us with all the required components.

Conflict of Interest

No conflict of interest was declared by the authors.

References

Giacovelli C. (2018). Single-Use Plastics: A Roadmap for Sustainability (rev. 2). https://www.unep.org/resources/report/single-use-plastics-roadmap-sustainability

Andrady AL, Neal MA (2009). Applications and societal benefits of plastics. Phil. Trans. R. Soc. B364, 1977–1984. doi: 10.1098/rstb.2008.0304

Padervand M, Lichtfouse E, Robert D, Wang C. (2020). Removal of microplastics from the environment. A review. Environ Chem Let. 18(3): 807-828. https://doi.org/10.1007/s10311-020-00983-1

Azoulay D, Villa P, Arellano Y, Gordon MF, Moon D, Miller KA, Thompson K. (2019). Plastic & health: the hidden costs of a plastic planet. CIEL. https://www.ciel.org/wp-content/uploads/2019/02/Plastic-and-Health-The-Hidden-Costs-of-a-Plastic-Planet-EXECUTIVE-SUMMARY-February-2019.pdf

Wall RW, Bennett J, Eis G. Creating a low-cost autonomous vehicle (2002). IEEE 2002 28th Annual Conference of the Industrial Electronics Society. IECON 02, 2002; 3112-3116. **DOI:** 10.1109/IECON.2002.1182894

Anderson JM, Nidhi K, Karlyn DS, Paul S, Constantine S, Oluwatola TA (2016) Autonomous Vehicle Technology: A Guide for Policymakers. Santa Monica, CA: RAND Corporation. **DOI:** https://doi.org/10.7249/RR443-2

Nielsen KM, Andersen P, Pedersen TS, Bak T, Nielsen JD (2002). Control of an autonomous vehicle for registration of weed and crop in precision agriculture. Proceedings of the International Conference on Control Applications, 909-914. **DOI:** 10.1109/CCA.2002.1038723

Naranjo JE, Clavijo M, Jiménez F, Gómez O, Rivera JL, Anguita M. Autonomous vehicle for surveillance missions in off-road environment (2016). 2016 IEEE Intelligent Vehicles Symposium (IV); 98-103. **DOI:** 10.1109/IVS.2016.7535371

Yu JJQ, Lam AYS. Autonomous Vehicle Logistic System: Joint Routing and Charging Strategy (2018). IEEE Trans. Intell. Transp. 2175-2187. **DOI:** 10.1109/TITS.2017.2766682

Arai Y, Miyagusuku R, Ozaki K. Development and Testing of Garbage Detection for Autonomous Robots in

Outdoor Environments (2021). 2021 IEEE/SICE International Symposium on System Integration; 138-143.
DOI: 10.1109/IEEECONF49454.2021.9382646

Evan A., Volvo Takes the Right First Step in Autonomous Garbage Collection. IEEE Spectrum, 2017.

Jha A, Singh A, Kerketta R, Prasad D, Neelam K, Nath V. Development of Autonomous Garbage Collector Robot. In: Nath V., Mandal J. (eds) (2019). Proceedings of the Third International Conference on Microelectronics, Computing and Communication Systems. Lecture Notes in Electrical Engineering, (556). Springer, Singapore. https://doi.org/10.1007/978-981-13-7091-5_46

Mayorga C, et al. GABOT: Garbage Autonomous Collector for Indoors at Low Cost (2019). 2019 International Conference on Mechatronics, Electronics and Automotive Engineering (ICMEAE), 56-61. DOI: 10.1109/ICMEAE.2019.00018

Banu NMI, Florence SM. Convergence of Artificial Intelligence in IoT Network for the Smart City—Waste Management System. In: Jeena, JI, Gonzalez-Longatt FM, Kolandapalayam SS., Izonin I. (eds) (2022). Expert Clouds and Applications. Lecture Notes in Networks and Systems;(209). Springer, Singapore. https://doi.org/10.1007/978-981-16-2126-0_21

Divya B V and Latha N, "Smart Garbage Collection Autonomous Vehicle," 2021 4th International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE), Noida, India, 2021, pp. 615-618, doi: 10.1109/RDCAPE52977.2021.9633553.

Pyo J-W, Bae S-H, Joo S-H, Lee M-K, Ghosh A, and Kuc T-Y. Development of an Autonomous Driving Vehicle for Garbage Collection in Residential Areas. Sensors. 2022; 22(23):9094. https://doi.org/10.3390/s22239094

Ying Wang, Xu Zhang. Autonomous garbage detection for intelligent urban management. MATEC Web Conf. 232 01056 (2018) DOI: 10.1051/matecconf/201823201056

Kulshreshtha M, Chandra SS, Randhawa P, Tsaramirsis G, Khadidos A, Khadidos AO. OATCR: Outdoor Autonomous Trash-Collecting Robot Design Using YOLOv4-Tiny. Electronics. 2021; 10(18):2292. https://doi.org/10.3390/electronics10182292

Assis A, Biju A R, Alisha N, Dhanadas A, Kurian N. Garbage Collecting Robot Using YOLOv3 Deep Learning Mode. 2021 International Conference on Advances in Computing and Communications (ICACC), Kochi, Kakkanad, India, 2021, pp. 1-5, doi: 10.1109/ICACC-202152719.2021.9708298.

Bai J, Lian S, Liu Z, Wang K, and Liu D., Deep Learning Based Robot for Automatically Picking Up Garbage on the Grass. in IEEE Transactions on Consumer Electronics, vol. 64, no. 3, pp. 382-389, Aug. 2018, doi: 10.1109/TCE.2018.2859629.

Huang X R-, Chen W H, Pai W Y, Huang, G Z, Hu W C, and Chen L B. An AI Edge Computing-Based Robotic Automatic Guided Vehicle System for Cleaning Garbage," 2022 IEEE 4th Global Conference on Life Sciences and Technologies (LifeTech), Osaka, Japan, 2022, pp. 446-447, doi: 10.1109/LifeTech53646.2022.9754931.

Aydın O, Molla E, Karadağ F, Güzeltepe B. (2021). Autonomous Garbage Vehicle for Public Parks. BSc, Eskişehir Technical University, Eskişehir, Turkey.

Zhao ZQ, Zheng P, Xu ST, Wu X. (2019) Object detection with deep learning: A review. IEEE T Neur Net Lear. 30(11): 3212-3232.
DOI: 10.1109/TNNLS.2018.2876865

Zou Z, Shi Z, Guo Y, Ye J. (2019). Object detection in 20 years: A survey. arXiv preprint arXiv:1905.05055. https://doi.org/10.48550/arXiv.1905.05055

Tivelius M. (2021) Real-time Small Object Detection using Deep Neural Networks. MSc thesis, KTH Royal Institute Of Technology School, Stockholm, Sweden. https://www.diva-portal.org/smash/get/diva2:1587035/FULLTEXT01.pdf

Redmon J, Divvala S, Girshick R, Farhadi A. (2016). You only look once: Unified, real-time object detection. In: IEEE conference on computer vision and pattern recognition, 779-788. https://www.cv-foundation.org/openaccess/content_cvpr_2016/html/Redmon_You_Only_Look_CVPR_2016_paper.html

Park HJ, Lee S, Yun S, Kim H, Kim W-T. (2019) Dependable Fire Detection System with Multifunctional Artificial Intelligence Framework. Sensors; 19(9). Doi: 10.3390/s19092025

Savla DV, Parab AN, Kekre KY, Gala JP, Narvekar M. (2020). IoT and ML based Smart System for Efficient Garbage Monitoring: Real Time AQI monitoring and Fire Detection for dump yards and Garbage Management System. Third International Conference on Smart Systems and Inventive Technology (ICSSIT).
DOI: 10.1109/ICSSIT48917.2020.9214202