AI Capstone Project – AIGC-5505-IRA

Literature review
Kevaras autonomous services

By:
Tech Titans

Project Introduction:

Littering remains a significant environmental challenge, impacting urban cleanliness, public health, and ecosystems. Traditional methods for detecting and managing litter often rely on manual labor, which can be inefficient and costly. The increasing availability and capability of Artificial Intelligence (AI) and Machine Learning (ML) technologies present a transformative opportunity to address these challenges. Through the use of machine learning algorithms and computer vision techniques, it is possible to develop automated systems capable of detecting and classifying waste in real-time, offering a more efficient and scalable solution to litter management.

This literature review explores the integration of machine learning and computer vision in the development of such automated systems. Specifically, it focuses on the application of deep learning models for the detection of litter from various camera angles, as proposed in the capstone project for Kevares Inc. The project aims to leverage state-of-the-art AI tools to enhance environmental monitoring and waste management processes.

By examining prior work in the field, this review provides insights into the methodologies and technologies that have been successfully implemented in similar projects. It also identifies the challenges and limitations faced in deploying these systems in real-world environments. The objective is to synthesize existing knowledge, highlight gaps in current research, and suggest directions for future studies to further advance the development of automated litter detection systems. Through this, the project not only contributes to academic learning but also addresses a critical need in urban management, paving the way for smarter, cleaner cities.

Company introduction:

Kevares Autonomous Services, founded in 2019 and incorporated in 2020, is an Ontario-based startup specializing in autonomous mobile robots designed to perform a variety of services, including inspections, lawn mowing, litter collection, and snow removal. By leveraging electric-powered robots, Kevares contributes to reducing carbon footprints and enhances operational efficiency by allowing clients to reassign personnel from repetitive or hazardous tasks to more critical responsibilities.

The company's platform enables the control and delivery of services via autonomous robots, regardless of the manufacturer. This flexibility allows municipalities and businesses to improve their monitoring and maintenance operations through autonomous services offered in a Robot-as-a-Service (RaaS) model.

Kevares has established significant collaborations to advance its technology and expand its market presence. Notably, within a year of incorporation, the company secured a two-year $240,000 research and development project in robotics and AI with the Ontario Centre of Innovation and Queen's University. Additionally, Kevares received $50,000 worth of AI training at the University of Toronto's data center. The company has also partnered with the City of Oshawa and Oshawa Teaching City for its first autonomous sidewalk inspections project.

Under the leadership of Founder and CEO Joel Nascimento, Kevares continues to innovate in the field of autonomous services, aiming to bridge the complex gaps in self-driving robots, human-machine integration, and last-mile mobility. By offering services on top of autonomous mobile robots, Kevares provides clients with efficient, scalable, and environmentally friendly solutions for various operational needs.

Prior Work/ Literature

Let's look into some previous work done related this field and industry.

1. **Autonomous, onboard vision-based trash and litter detection in low altitude aerial images collected by an unmanned aerial vehicle.**
   Marek Kraft, Mateusz Piechocki, Bartosz Ptak, Krzysztof Walas. Remote Sensing 13 (5), 965, 2021
   - Public littering and discarded trash are, despite the effort being put to limit it, still a serious ecological, aesthetic, and social problem. The problematic waste is usually localised and picked up by designated personnel, which is a tiresome, time-consuming task. This paper proposes a low-cost solution enabling the localisation of trash and litter objects in low altitude imagery collected by an unmanned aerial vehicle (UAV) during an autonomous patrol mission. The objects of interest are detected in the acquired images and put on the global map using a set of onboard sensors commonly found in typical UAV autopilots. The core object detection algorithm is based on deep, convolutional neural networks. Since the task is domain-specific, a dedicated dataset of images containing objects of interest was collected and annotated. The dataset is made publicly available, and its description is contained in the paper. The dataset was used to test a range of embedded devices enabling the deployment of deep neural networks for inference onboard the UAV. The results of measurements in terms of detection accuracy and processing speed are enclosed, and recommendations for the neural network model and hardware platform are given based on the obtained values. The complete system can be put together using inexpensive, off-the-shelf components, and perform autonomous localisation of discarded trash, relieving human personnel of this burdensome task, and enabling automated pickup planning.

2. **Time Littering Detection—Using Pose Estimation and Object Detection.**
   R Kaladevi, K Ganesh, P Kishore, Raghavan V Vijaya. Disruptive Technologies for Sustainable Development, 156-160, 2024
   - Public littering is a huge problem in Developing nations currently. Even though the world governments have implemented various schemes and awareness programs to clean our surroundings, there are not many ways to prevent people from littering. We see every other street littered with garbage and there is no proper system in place to monitor and hold people accountable for littering. Hence this research aims to solve this problem by developing a real time Litter detection system which uses YOLO, Faster-RCNN and Human Action Recognition methods to identify if a person litters in real time using live footage from IP cameras and captures the face of the litterer if visible and flags them so we can

identify if they repeat their actions in the future. This data can be used by the authorities to hold the people who litter accountable for their actions, and it can also help us identify which places require a cleanup.

3. **Smart street litter detection and classification based on faster R-CNN and edge computing.**
   Ping Ping, Effendy Kumala, Jerry Gao, Guoyan Xu. International Journal of Software Engineering and Knowledge Engineering 30 (04), 537-553, 2020.
   - Cleanliness of city streets has an important impact on city environment and public health. Conventional street cleaning methods involve street sweepers going to many spots and manually confirming if the street needs to be clean. However, this method takes a substantial amount of manual operations for detection and assessment of street's cleanliness which leads to a high cost for cities. Using pervasive mobile devices and AI technology, it is now possible to develop smart edge-based service system for monitoring and detecting the cleanliness of streets at scale. This paper explores an important aspect of cities — how to automatically analyze street imagery to understand the level of street litter. A vehicle (i.e. trash truck) equipped with smart edge station and cameras is used to collect and process street images in real time. A deep learning model is developed to detect, classify and analyze the diverse types of street litters such as tree branches, leaves, bottles and so on. In addition, two case studies are reported to show its strong potential and effectiveness in smart city systems.

4. **A vision-based litter detection and classification using SSD MobileNetv2.**
   Archana Balmik, Subhasish Barik, Mrityunjay Jha, Anup Nandy. 2023 10th International conference on signal processing and integrated networks (SPIN), 180-185, 2023
   - Municipal solid litter generation has steadily increased significantly in recent years. To prevent waste from collecting in the environment, it is beneficial to clean up wastes and rubbish using autonomous cleaning equipment such as unmanned surface vehicles. Cleaning efficiency requires a high-accuracy and reliable object detection system. Many machine learning techniques are explored so far to produce litter recognition systems. There are few studies on the effectiveness of cuttingedge deep learning object detection algorithms in the domain of litter localization and detection. We propose a detection and classification module for five different waste objects in this research. The dataset is created by gathering photos from various sources and under various environmental conditions at our Institute. In order to enhance the quantity of

data, data augmentation techniques are used. Image processing and feature extraction steps are applied to enhance the performance of the proposed model. The SSD MobileNetv2 model is employed for litter recognition which detects and identifies distinct contaminants and hazardous waste materials with a mean Average Precision (mAP) of 0.84. The proposed module aids in environmental cleanup by efficiently detecting the waste objects present in the surrounding environment

5. **Real-time Object Detection for Resource-constrained Autonomous Robots to Categorize Waste Materials.**
   Rajvi Tiwari
   - Pollution is a serious issue faced by the modern world. An analysis of the last five decades reveals that even though considerable attention has been focused on managing larger institutional sources of pollution, individual and crowd-oriented sources of pollution in the form of littering continue to be a pervasive problem worldwide. The 2020 Institute of Industrial and Electronics Engineers (IEEE) region 5 robotics competition was created with the purpose of utilizing robotics to help combat this particular issue of littering. With the goal to represent The University of Texas at Arlington (UTA) at the competition, our senior design team developed an autonomous robot that can recognize various litter items and safely collect and dispose them of in the appropriate bins. This work represents the research and implementation methodology used to integrate computer vision capabilities in the robot. It follows the comparative study of various object recognition models and optimization techniques, a thorough analysis of the team's hardware and resource constraints, and process of data collection and preprocessing. In addition to mere object recognition, object classification was carried out on a continuous, real-time video stream generated using a high definition (HD) Logitech C270 camera mounted on the robot. This video stream was decomposed to foundational frames and the chosen frames were processed by the object detection model to recognize pieces of litter. The identified litter object would subsequently be labelled as belonging to one of the four approved categories: bottles, chip bags, soda cans and paper trays. A bounding box is created in the video frame to identify the location of the litter and this information can be further utilized to navigate the robot to collect the item. Accurate classification also allows the robot to systematically store different categories of items by potentially integrating compartmentalizing hardware. This

systematic storage opens pathways to elevate the autonomous robot's functionality from basic collection/disposal to proper recycling of litter

6. **Research of an Enhanced YOLOv5-Based Algorithm for Garbage Detection in Service Areas.**
   Qichen Zhang, Hua He. 2024 4th International Conference on Neural Networks, Information and Communication (NNICE), 889-894, 2024
   - Addressing the challenge of effectively detecting service area litter through monitoring systems, this study introduces an improved YOLOv5 object detection algorithm. To begin, the backbone feature extraction network of YOLOv5 is replaced with the more powerful ResNet50, to enhance feature extraction capabilities. In addition to detect minute garbage more effectively, a dedicated small object detection layer is added, along with a corresponding feature extraction and fusion module. Furthermore, by removing the original large and medium object detection heads, the waste of computational resources is reduced, thereby accelerating the model's inference speed. Overall, NWD is introduced in place of the IoU loss function, further enhancing the detection accuracy for small objects. Experimental results demonstrate that the improved model excels in the task of service area litter detection, achieving an mAP0.5 of 91.95% and a 5.02% increase compared to the original YOLOv5s model, with a detection rate of up to 72 frames per second. Compared to other mainstream object detection models, the method of this study shows superior performance in both detection accuracy and inference speed.

7. **Litter detection with deep learning: A comparative study**
   Manuel Córdova, Allan Pinto, Christina Carrozzo Hellevik, Saleh Abdel-Afou Alaliyat, Ibrahim A Hameed, Helio Pedrini, Ricardo da S Torres. Sensors 22 (2), 548, 2022
   - Pollution in the form of litter in the natural environment is one of the great challenges of our times. Automated litter detection can help assess waste occurrences in the environment. Different machine learning solutions have been explored to develop litter detection tools, thereby supporting research, citizen science, and volunteer clean-up initiatives. However, to the best of our knowledge, no work has Investigated the performance of state-of-the-art deep learning object detection approaches in the context of litter detection. In particular, no studies have focused on the assessment of those methods aiming their use in devices with low processing capabilities, e.g., mobile phones, typically employed in citizen science activities. In this paper, we fill this literature

gap. We performed a comparative study involving state-of-the-art CNN architectures (e.g., Faster RCNN, Mask-RCNN, EfficientDet, RetinaNet and YOLO-v5), two litter image datasets and a smartphone. We also introduce a new dataset for litter detection, named PlastOPol, composed of 2418 images and 5300 annotations. The experimental results demonstrate that object detectors based on the YOLO family are promising for the construction of litter detection solutions, with superior performance in terms of detection accuracy, processing time, and memory footprintLitter detection from digital images using deep learning

8. **Litter detection from digital images using deep learning**
   Jianfeng Liu, Chen Pan, Wei Qi Yan. SN Computer Science 4 (2), 134, 2022
   - In order to achieve automatically litter detection in residential area, machine vision has been applied to monitor environment of surveillance. Based on our observations and comparative analysis of the current algorithms, we propose an improved object detection method based on Faster R-CNN algorithm and achieve more than 98% accuracy of litter detection in surveillance. Through our observations, most of litters are small objects, we apply feature pyramid network to Faster R-CNN and optimize it by merging different layers by using multiply operate. Besides, we replace cross-entropy loss function with focal loss function to solve the problem of anchor imbalance by using region proposal network (RPN) and offer attention module through RPN to feedback the whole network. We collected more than 8000 labeled images from our surveillance videos for model training. Our experiments show that the improved Faster R-CNN achieves a satisfied performance in real scene.

9. **Efficient Deep Learning Models for Litter Detection in the Wild**
   Simone Bianco, Elia Gaviraghi, Raimondo Schettini, 2024 IEEE 8th Forum on Research and Technologies for Society and Industry Innovation (RTSI)
   - Littering presents a substantial environmental hazard and impacts our well-being. The importance of automatic litter detection lies in its ability to identify waste in the environment, thereby enhancing the efficiency of subsequent waste management operations. In order to achieve a comprehensive and detailed survey of an area for litter detection, one of the most effective approaches is to utilize the collective efforts of citizen science. In this work we assess the performance of the most efficient object detection methods aiming their use in

the type of devices typically employed in citizen science activities, e.g. smartphones with low processing capabilities. Experiments on the Trash Annotations in COntext (TACO) dataset show that by exploiting our training procedure, the efficient models that we tested are able to surpass the performance reached by larger models in the state of the art. Moreover, experiments show the among the efficient object detectors tested, the small model variants offer the best tradeoff between model size and litter detection performance.

10. Real-time Litter Recognition Using Improved YOLOv4 Tiny Algorithm

Shalini V, Shrikant Tangade, Prajna P K, Sangeetha J P, Farooque Azam, Anoop G L, 2022 IEEE 2nd Mysore Sub Section International Conference (MysuruCon)

- Littered roads have become a familiar sight in India. The main reason is the increasing population and inefficient waste disposal system. Since garbage collectors cannot pick litter in all the places, there is a need for an efficient way to detect it. Hence, a machine learning-based object detection model is used. In this, we have applied an improved YOLOv4-Tiny algorithm to detect the garbage, classify it and make the detection process easier on custom datasets. We have improved the algorithm in terms of the object prediction time, this is done by replacing a max pooling layer with one of two layers present in a fully connected layer. When an input is given, the algorithm detects the litter in the image with a bounding box around it along with the label and confidence score. The proposed model reduces the prediction time by 0.517 milliseconds less than the original algorithm employed which concludes that the object is predicted faster.

11. Hidden Challenge in Deep-Learning Real-Time Object Detection on Edge Devices

Marcus F. Nicolas, Dalila B. Megherbi, 2024 IEEE 67th International Midwest Symposium on Circuits and Systems (MWSCAS)

- As the need arises for edge intelligence, which combines edge-computing with artificial intelligence, efficient and accurate algorithms are increasingly needed. Edge computing allows AI applications to be executed in real-time, closest to hardware devices/systems, thus reducing latency that could be introduced if traversing the cloud or sent to some storage unit. The aim is the needed real-time information processing, among other benefits. Notwithstanding the advantages of Edge-AI, a challenge that is not generally addressed in many such real-time detection and recognition DL models is the effect of an object rotation on real-time object detection accuracy. In particular, object label uncertainty can

be introduced in rotated object detection because the detected shape is not foreseen. The focus of this paper is to highlight how real-time object detection can be affected by rotation, a problem of importance in the field. We selected a particular architecture, Efficientdet, and implemented it on a Raspberry Pi 4 to study this rotational object detection handicap. This paper also aims to increase awareness and tender possible solutions in hopes that future researchers and engineers can design DL models on edge computing devices that will significantly diminish the impacts of an object rotation on its real-time object detection accuracy.

12. YOLOV5-based target detection for ground litter picking robot

Qun Liu, Hongxia Yu, 2024 4th International Conference on Machine Learning and Intelligent Systems Engineering (MLISE)

- In order to create a good urban outlook, places such as scenic spots and parks urgently need the assistance of garbage picking robots, and this thesis proposes an algorithm to improve YOLOv5s for the classification and recognition of ground garbage, relying on the garbage picking robots based on vision technology. CARAFE up-sampling is introduced in the neck network, CARAFE can expand the sensory field, better utilize the information of the feature map, and reduce the occurrence of leakage detection; BiFPN feature pyramid structure is used to replace the FPN+PAN structure of the original network, and BiFPN can obtain more information about the underlying features, enhance the extraction ability of the detection network, and improve the detection effect of small targets; in order to make the model can be deployed to the hardware platform of the grasping system, lightweight convolutional PConv is introduced into the C3 module of the neck network to reduce the number of parameters of the algorithmic model and improve the detection efficiency of the algorithm; finally, the effectiveness of the improved YOLOv5s CBC is verified through experiments

13. Garbage Classification and Detection Based on Improved YOLOv7 Network

Gengchen Yu, Birui Shao, 2*023 International Conference on Pattern Recognition, Machine Vision and Intelligent Algorithms (PRMVIA)*

- With the improvement of people's living standards, garbage classification is gradually forced. However, due to people's awareness and knowledge, the classification accuracy and disposal of garbage are difficult to keep pace with guideline changes. With the consideration of the problems of low efficiency, heavy task and poor environment of garbage manual classification, an improved

YOLOv7 target detection method is proposed to realize the effective classification of garbage. In this study, the recursive gated convolutional gnconv was used to establish the HorNet network architecture, and the model was trained by making specific data sets. The C3HB module is added to the YOLO model, and the pooling layer is optimized to replace SPPFCSPC to improve the detection accuracy of the target. The experimental results show that the garbage detection and classification method proposed in this study has excellent accuracy. Experiments show that the map value, accuracy and recall rate of the proposed model on garbage datasets are 99.25%, 99.33% and 98.03%, respectively, which are 1.50%, 3.99% and 1.41% higher than those of YOLOv7. The overall results are better than the original model.

14. Research on garbage detection and classification based on YOLOv8

Jie Xu, Xinsen Liao, Ningjie Zhang, Wenhan Lin, Jingde Huang, *2024 5th International Conference on Computer Vision, Image and Deep Learning (CVIDL)*

- In order to improve the identification efficiency of garbage cleaning, we improve the identification speed and accuracy by studying the data and models of garbage classification and detection, so as to achieve higher efficiency of garbage identification and cleaning. This can avoid making the robot unable to play its role due to unclear recognition. We chose YOLOv8 model for training and built a complete model system. The network supports multi-object recognition, has a simple network structure and training method, and improves the object detection speed. After 100 rounds of training, we finally got an accuracy of 86.88%. The YOLOv8 network model constructed in this paper has efficient detection ability and can identify the types of garbage with high accuracy.

15. YOLO Nano: a Highly Compact You Only Look Once Convolutional Neural Network for Object Detection

Alexander Wong, Mahmoud Famuori, Mohammad Javad Shafiee, Francis Li, Brendan Chwyl, Jonathan Chung*, 2019 Fifth Workshop on Energy Efficient Machine Learning and Cognitive Computing - NeurIPS Edition (EMC2-NIPS)*

- Object detection remains an active area of research in the field of computer vision, and considerable advances and successes has been achieved in this area through the design of deep convolutional neural networks for tackling object detection. Despite these successes, one of the biggest challenges to widespread deployment of such object detection networks on edge and mobile scenarios is the high computational and memory requirements. As such, there has been

growing research interest in the design of efficient deep neural network architectures catered for edge and mobile usage. In this study, we introduce YOLO Nano, a highly compact deep convolutional neural network for the task of object detection. A human-machine collaborative design strategy is leveraged to create YOLO Nano, where principled network design prototyping, based on design principles from the YOLO family of single-shot object detection network architectures, is coupled with machine-driven design exploration to create a compact network with highly customized module-level macroarchitecture and microarchitecture designs tailored for the task of embedded object detection. The proposed YOLO Nano possesses a model size of ~4.0MB (>15.1× and >8.3× smaller than Tiny YOLOv2 and Tiny YOLOv3, respectively) and requires 4.57B operations for inference (>34% and ~17% lower than Tiny YOLOv2 and Tiny YOLOv3, respectively) while still achieving an mAP of ~69.1% on the VOC 2007 dataset (~12% and ~10.7% higher than Tiny YOLOv2 and Tiny YOLOv3, respectively). Experiments on inference speed and power efficiency on a Jetson AGX Xavier embedded module at different power budgets further demonstrate the efficacy of YOLO Nano for embedded scenarios.

Conclusion

The capstone project by Tech Titans focuses on developing an automated litter detection system using machine learning and computer vision, tailored to meet the real-world needs of Kevares Autonomous Services. The literature review highlights the significant potential of AI technologies to revolutionize waste management by automating the detection and classification of litter, which is crucial for urban cleanliness and environmental protection.

Kevares Autonomous Services, with its innovative approach in deploying autonomous robots for various municipal and corporate services, provides a robust platform for implementing this AI-driven solution. The company's strategic partnerships and ongoing projects underscore its commitment to leveraging cutting-edge technology for sustainable urban management.

The integration of advanced object detection algorithms like YOLO and Faster R-CNN, as explored in the literature, demonstrates promising results in improving the efficiency and accuracy of litter detection. By addressing the challenges identified in previous studies, such as the need for robust datasets and real-time processing capabilities, the project aims to contribute to both academic knowledge and practical applications in environmental monitoring.

In conclusion, this project not only aligns with Kevares' mission of enhancing operational efficiency through autonomous solutions but also represents a significant step towards smarter, cleaner cities. The outcomes of this project have the potential to set new benchmarks in the deployment of AI for environmental management, paving the way for further innovations in autonomous urban services.

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