From Detection to Collection: Intelligent Garbage Cleaning Vessel Technologies

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Abstract. This paper focuses on offering a detailed overview of the main technologies and the latest developmental state of the intelligent garbage cleaning vessels due to the increased acuity of the pollution of water surface. The old manual salvage technique is also marked by a low efficiency level and a narrow exposure and thus cannot be used to address the large scale cleaning needs. Conversely, smart garbage-cleaning boats that play on their merits of extreme efficiency, automation, and accuracy are becoming popular as a necessary element of water surface environmental protection. This paper features a systematic review that focuses on the two cornerstones of the workflow, which are garbage collection and garbage detection. It studies the nature and use of sensor technologies in the field of garbage detection: of traditional physical feedback mechanisms, methods of vision detection using image recognition and deep learning, and data fusion based on the use of multiple sensors. In reference to the area of garbage collection, it explores mainstream methods like meticulous grasping through the use of robotic arms and centralized aspects through mesh bags as well as intelligent methods of garbage classification. Last but not the least, the article provides the present stage of development of intelligent garbage cleaning boats, the existing challenges and forecast of the further technological trends as well, which makes the articles a good source of references to the related research and practice.

Keywords: Garbage cleaning vessel, garbage detection, sensor, intelligent classification.

1. Introduction

Over the past couple of years due to the unending growth in the activities of mankind, the pollution of the aquatic habitat has taken a new and more serious form and thus the life of living organisms in the water is more than ever before becoming a serious challenge. Consequently, conservation of the surface water environments has emerged as a major concern that has attracted a lot of concern by international community. Thus, plastic waste and other pollutants have a critically important role that involves elimination in the marine and fresh water bodies or such as the oceans, lakes and rivers. The primary drawback of the traditional manual salvage techniques is that in addition to their labor intensity being extraordinarily intense, it is also limited due to the limited number of the human resource. Therefore, the applicability and efficacy of salvagement acts are acutely confined thus preventing the fulfillment of the needs of massive and viable surface water wastes management. It is against this context that smart garbage cleaning vehicles, capitalizing on their vast potential with respect to high efficiency, automation, and accuracy, have become the new front runners in areas like marine environment protection, and ecological recovery and usage have become highly prevalent [1].

The intelligent garbage cleaning vessel has a workflow that is mainly based on three steps namely garbage detection, collection, and sorting [2]. Among the above, garbage detection and collection are those fundamentals that allow autonomous functioning in intelligent garbage cleaning vessels. The use of sensor-based positioning technology and intelligent collection systems can be viewed as some of the enablers of efficient waste removal when applied in aquatic environments. The maturity of these systems in terms of technology directly affect the cleaning efficiency of the systems and level of system intelligence and operational reliability. Intelligent garbage cleaning vehicles are usually fitted with several sensors to determine the position and placement of floating garbage in the water body effectively in the garbage detection sector. Once the exact site of the garbage has been determined, the cleaning equipment uses a special mechanical collection apparatus to conduct garbage collection and delivery of the same. Varied collection techniques are used when cleaning the vessels depending on the type of waste. To cope with big plastic/metal debris, the cleaning ship has a robotic arm attached on the hull to assemble the specific item. Centralized collection is done through mesh bags in instances where the biological waste is high and distributed heavily.

With the current area of the intelligent garbage cleaning vessels development and implementation, the purpose of this paper is to review and analyze the specifics of its operational workflow, especially in relation to the technological advancement on two stages of garbage detection and collection. This essay targets two areas, that is, garbage collection and detection. It includes systematic and extensive review of detection technology, using conventional sensors and machine vision, mainstream collection technology in mechanical collection, grasping and either sorting. Basing on the findings of current researches, the paper will commence by looking at sensor-based smart garbage detection technology. In particular, it mentions sensor technologies founded on the physical feedback and visual detection technologies that combine image recognition and deep learning, and multi-sensor data fusion technologies. Moreover, it recognizes the formation situations and the major peculiarities of every technology. The paper then dwells on intelligent garbage collection technology and expounds on the collection mechanism, accurate manipulation by the robotic arm and intelligent waste classification. Lastly, the paper will explain the current state of development of intelligent garbage cleaning vessels, its challenges, and the future trends of the same.

2. Sensor-based intelligent waste detection technology

Smart trash sensors can be regarded as a significant requirement to autonomous garbage cleaning trucks. Its fundamental operation is to utilize the multi-source sensing technology in order to develop precise positioning, correct identification, and successful classification of floating waste on the water surface. According to the variations in sensor types and technological strategies, the existing mainstream sensing systems may be categorized into three broad groups, namely, sensor-based detection systems using physical feedback-based mechanisms, the visual information detection systems, and multi-sensor fusion detection systems.

2.1. Sensor-based detection using physical feedback mechanisms

The widely used technical methods in the sensor-based detection technique which involves use of physical feedback mechanisms include the use of infrared, ultrasonic, and lidar sensors. The sensor sends signals to the area near the hull and interprets the reverse transmitted information to establish the location and nature of floating trash. Consequently, the garbage cleaning ship will be able to conduct detection functions in different visibility configurations [3].

As a result of the high environmental flexibility of this kind of sensor, over the past years, most mainstream sensors in the market have integrated this physical signal feedback system in the initial stage of detecting garbage and estimating the distance to the position of the object. As an example, ultrasonic sensors are able to calculate the exact distance of floating debris and the cleaning vessel when they are transmitted and received. This sensor is made of a transmitter and a receiver which are the basic building blocks of this sensor. It is common in automated activities especially in measurement of spatial physical data like distance and position. When it is working the sensor sends out pulses which are very short and when the sensor receives the signal it counts the time difference between when the pulse is emitted and when the signal is received. According to this time difference and the speed of propagation of the ultrasonic waves, the distance between the cleaning vessel and the target debris is then determined using an already defined formula.

$$s = \frac{v \times \Delta t}{2} \tag{1}$$

Here, s denotes the distance, v denotes the speed of propagation of the ultrasonic waves, and Δt denotes the time difference. Also, the value of the v differs in relation to medium and temperature [4]. In the meantime, the ultrasonic measuring of distance is not as sensitive to the color and texture of objects. It is also able to treat even difficult materials like liquids, transparent, bulk materials and glass with high accuracy in detection and thus save the cleaning vessel the trouble of ensuring it can maintain high performance in detection [5]. Nonetheless, in terms of various environmental factors that the garbage cleaning ships will be exposed to, there is a need to devise the adaptive strategies, which will enable the accurate detection of ultrasonic sensors in a multi-media environment. The paper [6], discusses a study regarding the distance measurement scheme of the ultrasonic sensors within a dual medium environment. It examines the variations in the attenuation properties of ultrasonic waves in two different media namely water and air and suggests that two types of echo signal conditioning circuits be used. To provide accuracy in detection, ultrasonic echo detection system converts echo signals to digital form by the use of high speed of analogue-to-digital (AD) conversion. It further uses analogue sampling that gains amplitude of echo signals on each cross-section, which is used as the reference voltage to set up the echo detection threshold. This system is identified together with the echo signal conditioning circuit so that the intelligent garbage cleaning vessel can detect the environment of a dual medium water-air with great reliability and accuracy. There are, however, some limitations of the system. The performance capabilities of ultrasonic sensing in close range detection situations have been short of the intended performance criteria.

Like the ultrasonic sensors, an intelligent garbage cleaning vehicle that uses infrared sensors and Light Detection and Ranging (LiDAR) as detectors of the garbage must also have the capacity of using emission and reception of signals to detect the distance and the azimuth of the target. Infrared sensors use thermal energy to ascertain the waste existence. They are also stable at low-light situations and even at night, thus are spearheaded at low-visibility situations. The features of infrared sensors are analyzed in reference [7]. The features of these sensors include low prices and rapid speed of response. They are, however, nonlinear in nature and there is a vulnerability of the results of their measurements to the surface reflectivity of the target objects. The LiDAR (Light Detection and Ranging) develops a high-resolution three dimensional map of the surrounding environment of the cleaning vessel by emitting laser beams and echo responses. It has high accuracy of spatial positioning of objects, which allows it to detect garbage with high accuracy in the complicated aquatic conditions, especially where floating debris are concentrated. The LiDAR technology will be able to record the movement of small debris on the water surface at real time. At the same time, it is also not subject to ambient light or reflections on water surfaces, which is advantageously very stable and accurate. Lidar combined with infrared sensors can also make the detection of garbage more effective and more accurate under varying conditions, further increasing the ability of intelligent garbage cleaning vessels to be automated.

To sum up, the sensors powered by physical feedback mechanism have specific benefits in garbage detection in a complicated environment because of their specific technical concepts. The intelligent garbage cleaning vessel, with the combination and synchronization of various sensors, will have an opportunity to perform the effective and precise garbage detection in various aquatic conditions to deliver high-quality data assistance to the further garbage collection and classification processes, as shown in Table 1.

Table 1. Advantages and Limitations of Sensors in Common Physical Feedback Mechanisms

Sensors	Advantages	Limitations
Infrared sensor	Low cost, fast response, and high sensitivity in short-range detection	Highly susceptible to light interference and performs poorly in detecting transparent and smooth-surfaced objects.
Ultrasonic sensor	Low cost, insensitive to environmental factors such as light, colour, and transparency, and capable of reliable operation under adverse weather conditions.	The accuracy is relatively low, and it is susceptible to temperature variations and reflection interference.
LIDAR	High precision, wide measurement range, and strong anti-interference capability	The cost is high, and accuracy decreases under extreme weather conditions, including rain, snow, and dense fog.

2.2. Deep learning-based visual inspection

The visual inspection methods are mainly categorized into two major categories namely traditional image processing and automated processing which is deep learning-based. When applied to intelligent garbage cleaning vessels whose features dictate that the detection speed should be low, but the traditional image processors are highly sensitive to environmental changes, including illumination, water flow, and floating debris, which reduces the detection accuracy and efficiency of the process, the traditional image processing cannot be used in the intelligent garbage cleaning vehicle due to its high sensitivity to environmental changes. Thus, image recognition and deep learning technologies are the main elements of the visual detection approach of the intelligent garbage cleaning vessel wherein they can be utilized to classify floating debris on water surfaces correctly [8].

Over the recent years, more and more deep learning algorithms are being developed. Among these, one of the most representative methods is the one with the application of Neural Networks (CNN) in the domain of classifying and locating junk photos. Convolutional neural networks are usually made up of an input, convolutional, pooling, and an output layers. The input of the processing is the raw data in garbage pictures taken on the cleaning vessels. After the extraction of features at varying frequencies in the convolutional layers, the data are then subjected to the pooling layers that carry out the feature selection eliminating the dimensionality of features and consequently the amount of parameters. Lastly, the fully connected layer converts the feature maps obtained to the ultimate output of the network.

The convolutional neural network model training follows the principles of its working [9]. The output layer sketches the garbage detection task of the intelligent garbage cleaning vessel into an objective function and calculates the error between the desired and the real value, then propagates the error downward layer upon layer and controls the parameters. The process undergoes a cyclical repetition until the network model converges to bring out the required training effect. Image segmentation algorithm has been found to be one of these methods, which enhance object recognition accuracy and strength. The algorithm steps are to transform the original image into a format that can be readily processed by the algorithm and finally transform an image into a single vector expression using convolutional operations. The algorithm then makes use of the information to build the filtering tensors that precisely isolate the main object and the background in the picture, therefore, allowing the cleaning vessel to recognize debris in the medium conditions of water. In theory, the more elaborate the network structure, the more information can be represented, making the features derived by it more settled. ResNet architecture that was suggested by Microsoft has shown excellent results in the garbage recognition module and in fact, it was able to train a neural network up to 152 layers [10]. Nevertheless, network-based experimental results (VGG and GoogLeNet) have shown that the deeper the network in question and the greater the decrease in optimisation effectiveness, as well as classification accuracy. In order to make deep networks training work well, a new network architecture was added to the ResNet [11]. In networks that have less than 50 layers the basic building block is a BasicBlock. In scenarios where the layers of the network have to go past 50, Bottleneck structure is used, which can drastically cut on the number of parameters and demands. Though it is accurate it allows the models to converge higher speeds thus allowing more profound architectures to extract more diverse features. This eventually improves the accuracy of garbage recognition of the cleaning vessel. Also, the performance of the recognition model can be enhanced through the inclusion of an attention model.

Besides the convolutional neural networks, other popular deep learning architectures are the YOLO family of image recognition networks, U-Net and its derivatives [12], and the RetinaNet family [13]. All these models have led to tremendous advantages in the error reduction of water surface garbage detection, thus offering greater technical support to the garbage recognition component of the intelligent cleaning vessels. Using the example of YOLOv5, the model is structured into four layers, stipulating the input stage; backbone network, feature fusion network, and detection head. Based on the amount of depth and width of the network, there are four variants of YOLOv5, namely, YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5x. Wan Taotao et al. used YOLOv5s as the baseline model and optimized it in 3 ways which included the attention mechanism, network structure and loss function. They put forward the YOLOv5s-BSS model and demonstrated the practicality of the enhancement by ablation tests, thus, improving the garbage recognition ability of the cleaning vessel remarkably [14]. Nonetheless, there are still several issues that are common to such models. As an example, they have low levels of generalization ability and the lack of their robustness to work with novel forms of garbage or in new cases during activities in ship deck cleaning.

2.3. multi-sensor data fusion for detection

This is essential in the implementation of the multi-sensor data fusion technology to enhance the accuracy and efficiency of the garbage recognition system within intelligent cleaning vessels. The multi- sensor data fusion involves the combination of multiple sensor representations, which offers more detailed feature representations. This increases the quality of garbage recognition of waters. Besides, it lowers the risk of misinterpretation due to interference of sophisticated aquatic surroundings with single-modality sensors that lower considerably the dependability of the detection system of the cleaning vessel and its environmental adaptability.

The intelligent cleaning vessel is a multi-sensor fusion system whereby the perception data of several sensors may be combined, through infrared, ultrasonic, LiDAR and vision sensors, to name a few. As an example, it uses, among others, Kalman filtering, Bayesian estimation, and a network of deep learning to accomplish the spatio-temporal alignment and complementary integration of information collected by various sources. This successfully manages the shortcomings of individual sensors in term of choosing range, accuracy and environmental adaptation, which subsequently assures strong garbage identification power of the smart cleaning gadget in the various water settings.

The Kalman filter can generally be executed in two steps, i.e. the prediction and correction. In the framework of the multi-sensor information fusion technology, it is not only a particular algorithm but also a very effective systemic solution. It uses the mathematical approach of iterative recursive calculation to give a statistically optimal estimate of the fused data and hence, proper processing of garbage data by the cleaning vessel. The functions of the Kalman filter in multisensor information processing have been discussed in [15]. A prediction-correction closed-loop is used in the single sensor local processing level to create estimates of both prior and posterior probabilities, therefore, allowing the generation of high accuracy local tracking whilst using just a single sensor and producing initial probabilistic input to a multi-sensor fusion. On the one hand, means and covariances local tracking results are made as input to fusion algorithms like GMD at the multi-sensor fusion level. Conversely, in centralized architecture, data of several sources are directly fused to obtain an ideal fusion and result in a globally optimum estimate of the target state.

The multi-sensor data fusion algorithm is a Bayesian estimation approach which incorporates prior knowledge with the multi- sensor observation data in estimating the floating garbage position on the water surface in probabilistic terms. Due to the adequate identification of the previous probability and the probability function, optimal performance on data fusion can be anticipated, and therefore, accurate identification and location functions of the intelligent cleaning vessels may be promoted [16]. Based on the real world circumstances, malfunctions of sensors, inherent limitations of the sensors and environmental issues at the water surface can cause a high rate of inaccuracy or inconsistency of data offered by sensors. In the original Bayesian conditional probability density function based on the normal distribution a reference [17] suggested a modified version where another factor F_{ac}

$$F_{ac}=\left\{\frac{m^2}{m^2\text{-}(z_1\text{-}z_2)^2}\right\} \tag{2}$$

F_{ac} is added. In this case, m is the maximum anticipated difference of the readings of the sensors. This is what enables one to adjust the probability distribution with respect to the difference between sensor measurementsand.

Multi-sensor fusion system has also greatly enhanced the recall rate and strength of garbage detection hence giving a great support to long-term and stable operation of intelligent cleaning vessels in dynamically varying aquatic environment. Indicatively, the visual detection system can be easily affected by interference when high light conditions are involved, but LiDAR is able to produce consistent distance measurements. The combination of the two sensors will be used to provide constant garbage detection to smart cleaning bins. Radar detection will be able to obtain the data concerning the amount and the position of floating waste on the surface of the water, whereas visual detection will give the data regarding the type of waste. The comparison of the outcomes of these two modalities makes the perception of the environment more complete and accurate, which will help to make informed decisions in the collection by cleaning vessels. When using the infrared vision, the LiDAR can be effectively employed to identify the floating garbage on the water surface during nighttime operations. Sensor fusion uses sensor fusion to combine the detection outputs of the sensors to produce multi-dimensional target information by improving the target detection performance of individual sensors that rely on infrared vision or LiDAR. This combined method of perception improves the environmental perception ability of cleaning vessels in unfavorable lighting circumstances including the night and backlighting.

3. Waste Collection Technology

Smart picking up is the last stage of execution of smart cleaning vessels in their cleaning process. Operational design and efficiency of this level has a direct effect on the overall cleaning performance. The collection modes used by cleaning vessels vary depending on differences in the nature of wastes and operating environments. Among the most common technologies in use today to collect food can be grouped into three basic areas: a mechanized centralized collection, high accuracy of robotic arm grip, and automatic sorting.

3.1. Mechanical centralized waste collection

In the case of the water surface waste that is relatively concentrated in distribution and of low recycling value, intelligent cleaning vessels have the ability to utilize mechanical cleaning systems, like conveyor belts, net-type capture mechanisms, or suction devices, to attain the constant and high-scale conversion of the water surface waste to the hull. During the forward movement of the conveyor belt, the cleaning vessel will be able to direct floating waste on the surface to the salvage area by modifying the immersion depth and inclination angle of the conveyor belt. Since the conveyor conveyor will keep running, the waste will be picked up upwards and then they will be moved into the garbage hold to have all the garbage stored in one place. The type of garbage collector called net-typeasi is dependent on the interception and scooping action of the net structure which is used to collect floating waste on the water surface. When the collection vessel moves, a net is deployed at the collection point (or even close to the water) to scoop the debris through the net. The waste thus obtained is further moved by means of lifting or flipping the net. Suction water cleaning works retrieve floating debris on water surface according to the principle of negative pressure vacuum. This is done by the production of a strong suction force in a motor mechanism to bring air and waste into the pipeline, then gas and solid separation is carried out. The most widely used form of centralized collection devices is the conveyor belt-based system of retrieval, which are used the most frequently. As reference [18] suggests, since the conveyor belt should be submerged in water to a specific extent, there is a possibility of the belt slipping because of the drive and therefore, the transmission efficiency is not high. A conveyor chain structure can be used to replace the conveyor belt to address the problem of transmission slippage.

It is interesting to note that the availability of an intelligent garbage cleaning equipment with solid-wing conveyor belt can either be advantageous or not, in terms of the effectiveness of surface waste collection. It was found, according to pertinent experimental data regarding the collection efficiency of marine debris with solid-wing conveyors, as reported by Erik Sugianto and Jeng-Horng Chen of National Cheng Kung University [19] that of the arguably three models, specifically, the model without wing-plates, the model with 12.5cm long solid wings, and the model with 18.75cm long solid wings, the model with 18.75cm wing plates registered high efficiency in collection of artificial marine debris (AMD), then the model with 1 As can be observed, the longer the solid wings attached on the cleaning vessel the more the quantity of AMD that can be gathered. It can be attributed to the fact that the longer wings form a greater collection area meaning that it has a higher ability to capture more AMD. Secondly, the slower the pace at which the intelligent garbage cleaning vessel is operating, the faster the AMD collection rate.

In the case of some forms of fairly scattered floating rubbish on the water surface, it is possible to enlist the assistance of the wave energy to focus the debris so that it can be collected with the help of a conveyor belt by the cleaning vessel. The design of washing the garbage with the help of waves will be reported on in reference [20] and suggested the possible mechanism of control. The garbage collection by waves is entirely powered by wave energy as its energy source and is obtained by the combined activity of three significant processes. First, in the floating body-ratchet mechanism, wave undulation is used. Once the buoy reaches a crest, it compels the drive shaft to rotate at the anti-clockwise direction. Once the wave crest has elapsed, the drive shaft spins clockwise making the ratchet slipping. Several buoy assemblies transform the energy of waves into an endless wave of mechanical energy to the drive shaft. This is followed by amplifying the speed of the gear set-differential mechanism with the principle of the large gear driving the small gear and combining asynchronous power provision by both sides through the differential system to provide a constant driving force. Lastly, the incomplete-tooth energy focusing process opens and closes the baffle of the garbage cleaning vessel thus focusing the waste ready to be picked by the conveyor belt. In spite of the fact that this design allows the vessel to complete the waste collection task using the conditions of energy conservation and environmental protection, some limitations exist. On the one hand, this design is very contingent on the condition of waves in terms of the power output. Whenever there is an occurrence of abnormal wave patterns, inconsistency in the debris collection, a blockage, or fluctuating collection performances might arise. The design on the other hand has a low operation efficiency on large water surfaces and low functional requirement.

To sum up, the mechanical centralized collection method has a straight forward structure and greater efficiency. Its structure allows the deployment of these vessels at large scale in cleaning up operations in the open waters to remove garbage in large numbers. The ease of the construction is not only helpful in saving maintenance prices, but also operational efficiency. Nevertheless, such approach ignores the potentials of utilizing some waste materials, does not ensure accurate collection of waste, and does not suit the use in the narrow navigable waterways.

3.2. Precise manipulation and grasping control of the robotic arm

To address a particular waterborne piece of debris or one which has a reasonably large value plastic bottles, aluminium cans, and metal containers the centralized collection approach frequently leads to the recyclable waste being mixed with non-recyclable content owing to late downstream sorting or incorrect classification. In order to reduce this problem, smart garbage cleaners usually use a specific collection approach where more effective and precise retrieval of recyclable resources is carried out. One of such methods, serving as a common practice towards bringing about accuracy in collection, involves using robotic arms in picking. This type of technical system usually is associated with rather strict requirements of the visual positioning accuracy. The article of [21] presents a new algorithm called Gaussian Process Regression (GPR) and its main features are: non-parametric flexibility and adaptive hyperparameters. The grasping process is proposed using a photometric method based on a monocular machine vision and Gaussian Process Regression to allow the cleaning vessel to have high-accuracy positioning. The system makes the positioning error between -0.90 and 0.80 mm improve to between -0.10 and 0.20 mm, the angular error between 0.06o and 0.06i coarse decrease to between 0.015o and 0.015i coarse. This positioning accuracy enhancement is essential in allowing the cleaning robot to accurately pick the objects under consideration by the robotic arm.

Along with the precise positioning, a good grasp onto the objects by the robotic arm involves the presence of force control as well. The power control policy of the arm-end of the robotic arm of the intelligent garbage cleaning vessel is very important in the efficiency of the work of surface waste collection. At the present, end-effectors used in mainstream can be categorized into three broad groups; rigid grippers, vacuum suction cups and magnetic fixtures. Both types of end-effectors would be applicable to particular waste collection tasks. Rigid grippers [22] find application in the industrial, automotive and maritime industries. The kind of end-effector is usually applicable to objects that have regular shapes and are very hard, and it offers a stable grasping behavior, as well as, simple mechanical design. It could not however grasp bendable or deformable objects and can tend to damage the target items easily. Vacuum suction cups are being used to collect and pick various items as end-effector with increasing popularity. There are two solutions to finding a vacuum source to vacuum suction cups, as suggested in reference [23]. The initial one is a vacuum pump that creates negative pressure, which is highly efficient, but it demands a lot of investment in hardware as well as complicated working procedures. The second one uses air compressor with vacuum generator which creates negative pressure due to high velocity airflow in accordance with Bernoulli principle. This approach has the advantages of low cost of investment, a small size, and that it is easy to operate hence the prevailing solution at the moment. This is however, its greatest disadvantage with excessive energy use. Considering the relevant merits and constraints of these two schemes, the Reference [23] offers a control solution to the vacuum suction cup system. Through the hysteresis control logic, it also gains high energy efficiency and low costs and also stability and reliability of the systems. The magnetic fixing [24] is easy to use and time saving. In addition, with the addition of further elements onto the magnetized materials it can improve the stability of clamping of the fixing. It is however, known to have a relatively small application range and is only applicable to most surface waste in water.

Despite the above three categories of end-effectors having their own specifics, the discovery of the flexible grasping technology has the important benefits of managing various, heterogeneous, and multi-structured wastes. With the help of this technology, the mechanical arm of the garbage cleaning vehicle is able to be more flexible to adapt objects of varying shapes, sizes, and material by replicating the flexability and compliance of life. According to the studies on the topic and experiments performed, the system of the intelligent garbage cleaning vessel can effectively determine a flexible grasping and force - control strategy system of the end - effector of the mechanical arm with the help of a series of technologies, which include variable - stiffness design of bionic structures, multi - modal perception fusion, adaptive impedance control, dynamic contact modeling, deep learning optimization, and online self - correction. This greatly improves the flexibility and intelligence of the robotized arm of the cleaning vessel under complicated conditions.

3.3. Intelligent waste classification

The smart classification system is a new level created in the technology of waste collection. Its underlying role is that it allows real time detection and sorted waste either during or after the process of collection. In order to have a real-time sorting process of garbage collected, the intelligent garbage cleaning vessel may take advantage of the technologies, i.e., the ability of recognition and classification of the types of waste and materials using visual analysis and deep learning algorithms. Afterwards, using mechanical sorting devices, which may include push rods or pneumatic valves or property-based separation systems, recyclables, hazardous wastes and other debris go to separate collection containers.

An intelligent garbage classification system, which uses the YOLOv5 algorithm, is used in the design of the garbage classification system based on machine vision, as analyzed by Wei Xinze and peers at Wuhan Business University [25]. Through this system, the garbage-cleaning vessels are able to carry out more efficient and accurate waste classification and utilization to minimize the waste sorting environment, decreasing the levels of environmental pollution, and enabling the processes ofrecycle. The model is based on the YOLOv5 that is used to automatically detect the waste images. The model incorporates CBAM attention mechanism, thus improving its performance. The ASTM32 microcontroller operates the stepper motor to operate the sorting of the wastes according to the classification results. In the meantime, there are TVOC and infrared sensing modules that are mounted to check the internal climate of waste storage compartment on the cleaning vessel. This system combines a shallow learning model and an embedded component to have the intelligent garbage cleaning vessel meet major characteristics of enhancing recognition of garbage and maximizing the sorting environment.

Physical property-based sorting is important at the mechanical sorting level of garbage cleaning vessels. The essence of this system will be separation processes, which will be based on the differences in physical properties such as size, density, magnetism, electrical conductivity and the surface properties of materials. It has been mostly used in waste sorting and recycling of cleaning tanks. A detailed classification and analysis of different mechanical sorting methods in solid waste were performed by the team of Lappeenranta-Lahti University of technology [26]. Using the example of conductivity-based sorting technology, this technology can be further divided into three categories, which are eddy current sorting, triboelectric electrostatic sorting, and corona electrostatic sorting. The principle of Eddy current separation relies on the law of electromagnetic induction by Faraday. It uses changing magnetic field so as to generate eddy current and consequently, separate conductive materials. An application of the Frictional electrostatic separation uses triboelectric effect to divide materials of varying charge polarities. The electrostatic induction induced through corona electrostatic separation is achieved by use of a corona electrode and the conductive materials separated by use of a rotating roller through screening. Other related sorting methods are the X-ray sorting, gravity sorting and the magnetic separation. These sorting systems that are based on physical properties will support the intelligent garbage cleaning vessel technically to enable efficient waste sorting.

Besides the mentioned technologies, there are more sophisticated systems that include data records and cloud-based communication opportunities and allow the intelligent garbage cleaning vehicles to conduct the full statistical analysis of the sources, types, and volumes of garbage. This is valuable data support on waste management and use of resources. The combination of functionalities of detecting, collecting, and classifying has greatly contributed to the level of intelligence and total performance of garbage cleaning vessels.

4. Conclusion

The presentable paper is a systemic review of the recent technological development level of intelligent garbage cleaning vessels on two main fronts, namely, garbage detection and garbage collection. In addition, the relevant technologies are discussed in-depth. Physical feedback mechanism-based sensors, visual detection-based sensors relying on deep learning, and multi- sensor fusion technology-based sensors placed upon intelligent garbage cleaning vessels all become part of a multi-level and complementary surface waste perception system in respect of waste detection. The system is able to efficiently and correctly address the need of waste detection in various aquatic environments. Intelligent garbage-cleaning vessels can offer a wide solution in waste collection by mechanical centralized collection, careful arm-grasping robots and intelligent waste sorting mechanisms in large scale collection or specific recycling were used. This will help bring about the smarter rubbish cleaning ships of simple and primitive cleaning processes to an advanced detection-gathering-classification-reusing design. This leads to high levels of efficiency and intelligence in aquatic waste management and reuse rate of the surface waste is improved.

Despite the considerable research and advancement in the sphere of waste sensing and gathering the intelligent garbage cleaning equipment, it is difficult to identify the aquatic environmental pollution in real time. Using a combination of visual perception and natural language instructions, the VLA model allows a human-machine interaction to perform more efficiently and quickly, and break down a task and generate actions more effectively, enabling the cleaning vessel to be more adaptable to the demands of the larger and more complicated tasks and instructions.

As the perception, decision-making and execution technologies become increasingly intertwined, intelligent garbage-cleaning vessels will progressively transform into proper intelligence and networking. It has extensive application opportunities both in the natural water bodies like oceans, rivers and lakes and in artificial water bodies like urban landscape waters, ports, and reservoirs. The smart garbage cleaning would device can not only enjoyably optimize the ecological setting of water bodies, but also supply the requisite technical assistance to the creation of clever water area administration structures, hence becoming part of the achievement of world water environmental protection and long-term ecological growth.

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