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Latest Trends in Visual Manipulation and Navigation in Robotics

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***Abstract*—In recent decades, the term Robot has become more and more popular. A robot can be defined as a machine that is specifically built to complete certain tasks to help human-being. In order to successfully accomplish its task, the robot needs to receive input data and process it. Then, the processed data is used for manipulator-actions decision-making. The input data can vary from sound, temperature, vibration, touch, vision, etc. Among those input data, vision is arguably one of the most challenging data. This is because vision often needs detailed and complicated preprocessing before it can be used. In addition, vision data size is relatively larger compared to the other type of input data, making it more challenging to process considering the computational resources. In this paper, current research and future development trend of robotic vision were reviewed and discussed. Further, challenges and potential issues about robot vision, such as safety and privacy concerns, were also discussed.**

***Index Terms*—visual manipulation, visual navigation, robotics, robot vision, machine vision**

Introduction

A. *Terminology of the Machine, Robot, Computer Visions, and Image Processing*

BEFORE we go deep into the contents, let us take a look at the definition of machine vision, robot vision, computer vision, and image processing to avoid term confusion. Machine vision is the industrial use of vision for robot guidance, system control, and automated inspection, whereas robot vision is the use of the optical module and computer algorithms to enable robots to digest visual data from the outside world. However, in many cases, the terms machine and robot visions are used colloquially. Furthermore, computer vision is concerned with extracting features from images in order to comprehend them. Image processing techniques, on the other hand, are mainly employed to enhance the quality of an image, transform it to another format (i.e., histogram), or otherwise convert it for further processing [1].

In this paper, machine and robot visions are used interchangeably, while computer vision is the parent of robot vision and machine vision. Furthermore, image processing is referred to as the processing technique used in computer vision. The robot vision's family tree is shown in Figure 1.

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B. *Role and Parameters of Robot Vision*

Robot vision is definitely an important part of robotics, and its main role is acquiring and processing the data about the target object or its surroundings and then extracting the essential features for designing a robot action. In robot vision, there are parameters that users need to consider carefully. In its application, a small error can lead to a big fatality. Whether as simple as making the system not work properly, breaking the robot itself, or even injuring and threatening its user's safety. Authors [2] defined some parameters that are important in practice:

1. Precision

The precision level in a robot vision system should meet a certain standard. For example, in the semiconductor automation factory, the precision level should be on a nanometer scale or less. The precision can be determined by the resolution and error characteristics. Since precision has a tradeoff with the working range (i.e., distance) and visual field, an appropriate system design is necessary. One feasible solution is to employ multiple sensing units.

2. Speed

High-speed (or even real-time) operation is vital in a robot system that is implemented in the time-critical sector, such as the military defense system or autonomous vehicle. However, the computational speed is usually inverse proportionally with the algorithm complexity. On the other side, algorithm complexity can be proportional to the system's precision. Therefore, it is important to design the system with an appropriate algorithm and balance computational speed to achieve its objective properly.

3. Robustness against disturbance

It is necessary to have a robot vision system that is stable in every situation regardless of the environment. Factors such as environment temperature, light intensity, dust, vibrations, water drop, and noise can easily disturb the robot's vision stability. Moreover, robot vision systems also should be robust enough against security breaches such as system hacking and DDoS.

4. User friendly

A robot vision system should be designed such that non-expert users can operate the system easily. Hence, the number of parameters can be reduced, and the parameter adjustment can be made easier or even automated.

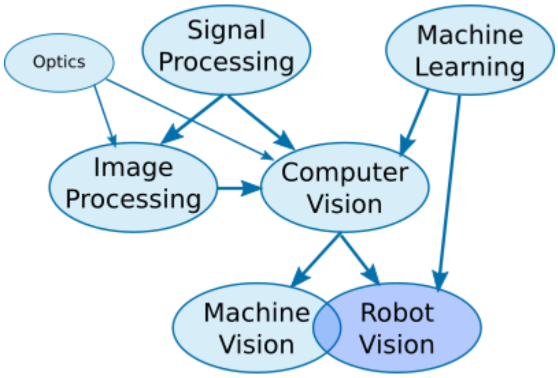

Fig. 1. Robot vision's family tree [1].

Latest Advanced Technologies in Robot Vision

A. Accuracy: Increasing Precision of the Iterative Closest Point

Authors [3] extend M-ICP [4], which comprehensively matches 3D shapes to outlying data (that is, including non-overlapping data or unexpected noise), and present an advanced example of a remarkably efficient and precise method for measuring complex 3D shapes with steep surfaces.

B. User-Friendly Operation: Hand-Eye Calibration with Minimum Viewpoints

Paper [5] introduced a technique for minimizing the number of viewpoints in order to make the system more user-friendly. The smallest number of viewpoints is determined solely by linear algebraic calculation without optimization and is used for calibration. Compared to the "prodding the marker" method, enhanced accuracy and operational time are obtained by the proposed technique.

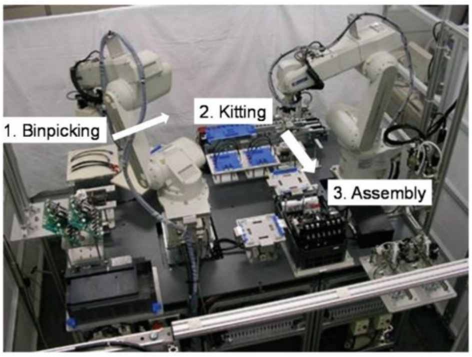

Fig. 2. Robot cell for assembling solid and flexible objects [6].

Latest Development Applications of Robot Systems with Vision

A. Robot Cell for Assembling Solid and Flexible Objects

A robot cell that can manipulate flexible objects is introduced [6]. In that paper, the robot is used to automatically assemble servo amps. Figure 2 depicts the robot's overall system. The recognized cord with a plug is selected from the supply desk and positioned on the top of the kitting area. The unidentified attitude of the flexible objects is resolved once the part has been kitted (that is, orderly laid out). This work hinted that conventional industrial robots that are appropriately taught could be used to perform assembly tasks in a logical manner.

B. Automated Bin-Picking Framework for Parts with Various Shapes

Previous studies have demonstrated that automating the manipulation of various-type components in the supply and bin picking of piled parts system is challenging. In an effort to mitigate this problem, research [7] showcases a robot cell that is able to deal with a piled-up supply of various parts. The robot is divided into four phases: pose estimation, pick and place, re-grasp, and insert phases. Figure 3 depicts the overall system of the proposed robot.

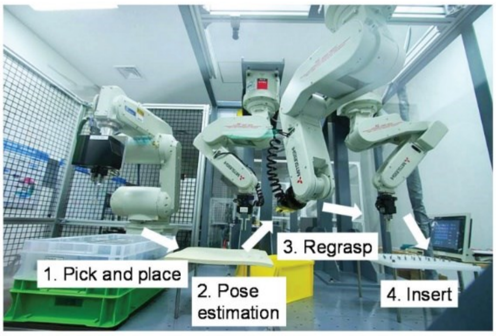

Fig. 3. Robot-cell performing bin-picking tasks for parts with various shapes [7].

Latest Trend and Future of Robot Vision

A. Vision Speed Improvement

How to increase the vision system speed is expected to be a research topic that will gain high interest in the robot vision area in the near future. The authors of [8, 9] have worked on high-speed image sensor elements and their corresponding high-speed image processing frameworks. As a result, new applications such as high-speed object recognition and high-speed robot control can be realized.

B. Deep Learning

Deep learning has become a popular research topic in pattern recognition and vision societies. This is evidenced by the large (and still rising) number of journals and symposiums devoted to the subject [10-15]. The exponential growth of technology, especially in computational power and storage in recent years, end the AI winter period. Researchers are working on datasets and the training methods of the NN algorithms that enable a paradigm shift in pattern recognition technique from conventional feature extraction techniques (i.e., HOG, LBP, etc.), which are usually combined with a statistical method such as linear regression to the utilization of data-driven modalities, where the features and classifiers are jointly learned with "very little engineering by hand" [13]. Table 1 shows some selected deep neural network (DNN) works on robot vision research.

Thanks to the decent adaptation of DNN algorithm evolution to the robotics applications' requirement, there is an explosion in the number of academic publications on deep learning applications in machine vision. Considering the large amounts of recent academic publications on deep learning applications in machine vision, we can expect that the deep learning utilization in the mentioned sector will rise in the near future.

TABLE I
SELECTED WORK ON ROBOT VISION USING DEEP NEURAL NETWORKS (DNN)

Author(s)	DNN Model and Distinctive Method	Application(s)
Bogun et al., 2015 [16]	DNN with LSTM techniques for videos' object recognition	Object Detection and Classification
Redmon et al., 2015 [17]	CNN algorithm based on AlexNet. The algorithm was trained on hand-labeled data with rectangle regression.	Object Grasping and Manipulation
Sung et al., 2016 [18]	DNN utilization for transfer manipulation in embedding space	Object Grasping and Manipulation
Alcantarilla et al., 2016 [19]	Deconvolutional Networks for Street-View Change Detection.	Scene Representation and Classification (Street-View Change Detection)
Tome et al., 2016 [20]	CNN algorithm (Alexnet vs GoogleNet) to detect pedestrian using LCDF as a person proposal	Object Detection and Classification
Husain et al., 2016 [21]	The output of a pre-trained VGG-16 is temporally concatenated into a 3D convolutional layer.	Spatiotemporal Vision (Action Recognition)

C. Federated Learning

With the growing size of datasets, together with the increasing complexity of the algorithm, implementing a robot vision system can become more challenging in resource-constraint applications such as autopilot UAVs, humanoid robots, etc. Therefore, a federated learning system can be implemented to alter such problems. Federated learning is a novel learning approach that enables data parties to collaborate on the development of machine-learning models whilst also maintaining their data private and secure [22]. The illustration figure of federated learning is shown in Figure 4. Paper [23] proposed a real-world image dataset for federated learning. The image dataset includes over 900 items obtained from 26 street camera systems and 7 object classifications, each annotated with a detailed bounding box. The authors of [24] introduce a federated learning model for obtaining different types of image representations from diverse tasks. These images are then combined to obtain fine-grained image representations. In [25], the authors reported FedVision - a machine learning technology system to assist in the development of federated learning-based computer vision applications. WeBank and Extreme Vision collaborated to develop the framework to assist customers in developing computer vision-based robust monitoring solutions for smart city applications.

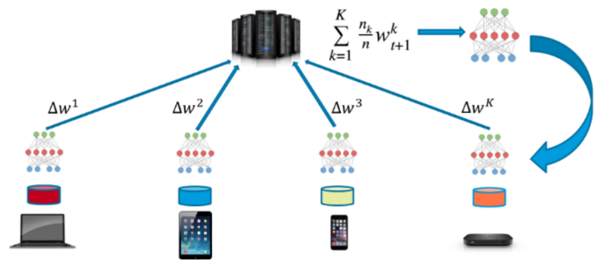

Fig. 4. Illustration of a federated learning [26].

D. Cloud & Big Data Robot Vision

Since the early 1990s, when the World Wide Web (WWW) was launched, the term "cloud" has been introduced as a metaphor for the internet. On the other side, "Big Data" refers to data sets that surpass the functionality of conventional relational database systems. "Big Data" refers to the internet's expanding library of images, videos, audio, texts, maps, and many other types of data relating to technology, robotics, and automation. [27]. Cloud computing combined with a big data database can be a promising solution for the robot vision application in the near future, considering the massive increase in dataset size and computation complexity over time. For example, research [28] proposed a model using intelligent optical systems to perform complex and advanced robot vision tasks in the cloud, while in [29], using stereo image processing, authors examined a tradeoff evaluation of a cloud-empowered robot navigation assistant. Moreover, it is also worth noting the application of autonomous vehicles and its future development plan made by [30], which is depicted in Figure 5.

RECENT ROBOT VISION IMPLEMENTATIONS

A. Medical Sector

Robot vision has been used in the recent development of medical technologies. For example, [31] introduces a robot vision innovation for digitalizing clinical diagnosis and treatment skills for the evaluation model of postoperative pericardial adhesion using cardiotocography. The author [32] proposed a system that combined the X-ray images with the 3D CT angiography model to assist the surgeon with 3D anatomical data for clinical cardiac intervention. Meanwhile, paper [33] proposed an AR-based navigation model for bone tumor resection procedures providing intuitive visualized information on resection margins. Furthermore, in [34], an integrated framework comprising an AR-assisted surgery navigation system and an endoscope holder to aid sinus surgery was proposed.

B. Industrial Sector

Robot vision has been used in the industrial area, especially factory automation, for decades, whether to separate goods (products) based on their type and size, to sort (quality control and quality assurance) such as separating defective products, or to control the production machine such as room temperature, machine speed, etc.

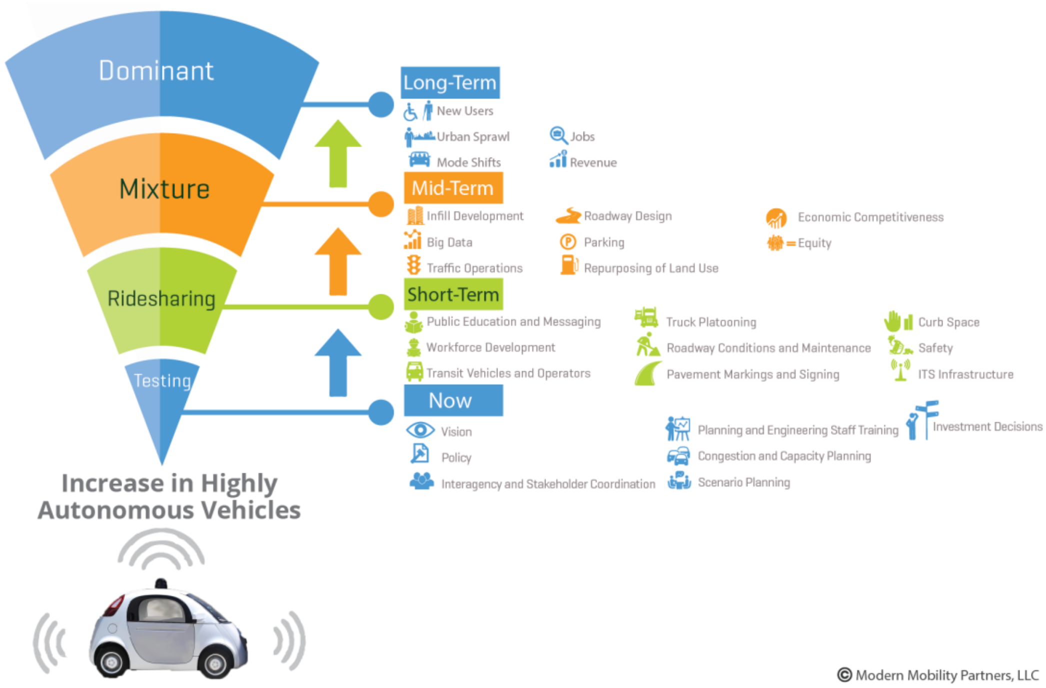

Fig. 5. Autonomous vehicle development plan [30].

Paper [35] used image processing and a robot manipulator as an industrial robot arm (ABB IRB 120) for QA assurance of process production. In that paper, an experiment is carried out to distinguish between normal and abnormal goods, that are substituted by 3D objects using an image processing model and an ABB industrial robot arm.

Paper [36] demonstrates a robot vision-based pick and place system using an ABB IRB 140 industrial robot and a webcam. The webcam is employed since the robot doesn't have an embedded color detection system when it comes from the company. The color sorting algorithm used in that work was created in MATLAB software using image processing and a computer vision toolbox. A web camera is used to identify the color of the input image. Following the DSQC IO card and relay module, the algorithm provides the controller with an intelligent solution to perform specific tasks for the robot. The introduced design uses image processing to provide real-time color detection and a pick-and-place strategy for object sorting.

As explained in Section IV, Subsection B, image processing using artificial intelligence/machine learning or deep learning is the future of robot vision. Reference [37] utilizes a probabilistic neural network (PNN) to solve the industrial robots' vision-based autonomous trajectory control. In that work, an autonomous trajectory control technique for industrial robots was proposed by utilizing the image recognition results based on the PNN (Probabilistic Neural Network) classification and NURBS (Non-Uniform Rational B Spline) trajectory planning.

C. Autonomous Vehicle

Since Tesla's appearance with its self-driving car in 2014, autonomous vehicle has become a hot issue. The autonomous vehicle is considered the future of transportation. In the current stage, an autonomous vehicle is heavily dependent on robot vision and image processing. However, the current stage of the autonomous vehicle is still far from perfect. There are several accidents involving autonomous vehicles [38-40]. At the moment, the accident rate of autonomous cars is still higher compared to that of human-driven vehicles. On average, the number of crashes per million miles driven by self-driven cars is 9.1, while it is only 4.1 for human-driven ones [41]. Hence, many researchers, both from academic and industrial backgrounds, are conducting research on robot vision for autonomous vehicles to minimize its safety risk. For example, research [42] proposed a monocular vision-based autonomous vehicle prototype using a deep neural network on raspberry pi. Author [43] proposed the design and development of intelligent autonomous vehicles using ROS and machine vision algorithms.

Image segmentation is a significant concern in visual perception in autonomous vehicles. Currently, the image segmentation method is primarily employed in clinical applications. However, recently, there has been a number of papers on image segmentation for autonomous vehicles. m the paper [44] used an image segmentation technique for visual perception tasks such as predicting agents in the environment, identifying street borders, and locating line markings. The primary goal of paper [44] is to split the input images using the image segmentation technique and the convolution neural network (CNN) algorithm for reliable and robust yet efficient visual perception results.

D. Other use

Other than what has been mentioned above, robot/computer vision is also used in many other sectors such as traffic control, disability people's aid, aid for the elderly, security, military defense system, etc. For example, [45] proposed a smart, automated system model for vehicle detection to maintain traffic by image processing. Research [46] builds a system to help the visually impaired person by using image processing for the identification and recognition of text and face. The author of [47] proposed a self-learning fall detection system for elderly persons using a depth camera, and [48] proposed an image processing technique for smart home security based on the principal component analysis (PCA) methods.

CHALLENGES

In image processing, there are plenty of computational challenges that need to be overcome. Among the challenges is the handling of image uncertainties that cannot be otherwise ignored, including incomplete, fragmentary, noisy, vague, not reliable, inaccurate, contradictory, deficient, and overloading information [49]. Fortunately, numerous advanced methods, including fuzzy networks, neural networks, and advanced filtering, have demonstrated great potential to mitigate the mentioned challenges. Therefore, in this section, instead of discussing those technical problems, we will discuss the challenge of image processing in terms of real-world applications. There are at least 3 major issues of image processing, which are computational speed, safety, and ethics & privacy concerns.

A. Computational speed

Image and video processing are the basics of robot vision. We know that video is comprised of a set of images, and the image is comprised of a set of pixels. The number of pixels is proportional to the quality of the image (resolution) and the image size. As already mentioned, deep learning will be the future of robotic and robot vision. It will be determined whether DNN methods can adapt to the demands of robotics development domains, like as high-speed operation with constrained embedded computational resources and the capacity to deal with limited observational conditions derived from robot geometry, sensors/actuators/objects relative attitude, and low camera resolution [50].

Currently, the computational power and memory overhead for most CNN models employed in vision applications have still become a barrier to their utilization in resource-limited robotic systems like as humanoid robots, UAVs, or even autonomous cars. Attempts have been made to develop CNN models that can be compressed and quantized to be used on resource-constrained platforms [51-52]. Furthermore, major technology manufacturers, including Intel, NVIDIA, and Samsung, are vying to develop CNN chips that will enable real-time vision-based applications [13]. It is predicted that such innovation will consolidate over the next few years and become available to robot vision engineers.

B. Safety concern

In this subsection, let us divide the safety issue into two parts. First is the safety related to the robot system performance itself. For example, in [53], where robot vision is used in a medical-surgical application, it can be dangerous for the patients if the robot experiences a failure in detecting the appropriate part of the human body. Therefore, it requires long research and validation steps to make sure the robot is safe enough to be implemented in the real world, which could hinder the development speed in such sectors. Another case is the autonomous vehicle. Let us recall the autonomous vehicle applications. As already mentioned, there are several accidents involving autonomous vehicle applications. In autonomous vehicle applications, the system should be able to handle a set of images from the camera of the vehicle, separate objects between humans, dogs, traffic signs, road limits, etc., and decide for the manipulators in a real-time manner.

Considering the accidents that happen, people's opinion is divided on whether the current development of autonomous vehicles is safe enough to be implemented on the road or not. The research [54] in 2015 concludes that: (1) Expecting zero fatalities from autonomous vehicles is unrealistic. (2) It is far from certain that an autonomous car will ever outperform an experienced, middle-aged driver in terms of safety. (3) Safety may actually worsen during the transition period, when regular and autonomous vehicles share the road, at least for conventional vehicles.

The second part is the safety related to the data breach or hacking. We might still remember the 911 accident, where a plane was hijacked by a terrorist and crashed into a WTC tower. We do not want such things or accidents to happen again. However, cyber-security has become one of the most potent threats to autonomous vehicles. The majority of the information will be contained within the vehicle, and an intruder can interfere with the information to lead to accidents. This is, indeed, a significant threat since terrorists or robbers can easily breach security, extract data, exploit the system, and cause massive mishaps [55]. Breach of the home surveillance cameras can be another example. If hackers or criminals are able to get into the surveillance system, it would be easy for them to get the personal information of the users and make use of it for blackmailing, criminal, etc.

C. Ethics & Privacy Concerns

There are growing concerns about privacy and ethic in future technology implementations, which is related to AI and robot vision as well [56-57]. For example, in a resource-constrained application such as UAV, CCTV surveillance, or even an autonomous vehicle, the computational resource might not be enough to compute the necessary data. Therefore, federated learning, where the data is uploaded to the central server, might be implemented. This could harm the privacy of the users as often the data that are uploaded contain some sort of personal privacy.

Ethics issue is another concern. Let us again consider the autonomous vehicle. Some of us might know the "trolley dilemma", where a runaway trolley hurtles down the tracks toward a group of workers who cannot hear it coming. As the disaster approaches, we notice a lever attached to the tracks. We then realize that if we push the lever, the trolley will be diverted down a different set of tracks that is away from the group of workers. However, there is one worker who is just as unaware as their colleagues. The question is: shall we push the lever, resulting in one fatality but saving the group? This dilemma might also occur in an autonomous vehicle, which is illustrated in Figure 6.

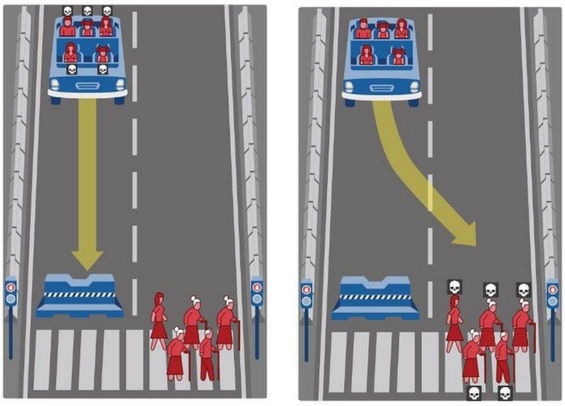

Fig. 6. Illustration of "trolley dilemma" on autonomous vehicle [58].

CONCLUSIONS

Robot vision is one of the technologies that is used massively in multiple sectors such as medicine, industrial, autonomous vehicle, UAVs, military defense, surveillance, etc. In the recent decade, together with the development of computational hardware and computational technique, robot vision has been developed massively. Considering the current and past few years' trends, it is expected that robot vision development will rely on AI/ML or deep learning implementation. It is also expected that federated learning-based robot vision, combined with big database/cloud computing, will become more familiar to users. Additionally, we might see a significantly faster robot vision system with higher accuracy and precision compared to the current latest robot vision system. Indeed, there are some challenges that exist for robot vision development, such as computational speed and safety/ethics/privacy concerns. However, we believe that robot vision is still a promising solution to many human problems.

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