# Artificial vision for manipulators: a review

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**Abstract.** Industrial robots cover most of the field of technology and are most successfully applied in machining, in motion modelling, in capturing and moving objects of research. More recently, industrial robots and robotic manipulators have become more complex, diversified and designed specifically to achieve a high level of autonomy compared to traditional mechanical manipulators. In this article the classification of different configurations of manipulators and analysis of manipulators with artificial vision on the existing research of scientists is conducted. Also, the article analyzes the development of a manipulator with six degrees of freedom and the use of analytical methods to analyze the geometric structure of 3D data for optimal object recognition.

**Key words:** manipulator, artificial vision, object recognition, modeling, degrees of freedom.

## I. INTRODUCTION

Recent progress in science and technology has led to the widespread use of robotic manipulators in various practical fields, including industrial production, domestic services, agriculture, health care, entertainment, military defense and even space exploration [1,2]. The main functional and operational capabilities of industrial robots are determined by the design of the manipulator: working area, manipulation, service ratio, loading capacity, etc. [3]. Industrial manipulator robots are widely used for repetitive, unmanageable human and complex tasks. Thus, increasing the efficiency of manufacturing industrial robotic manipulators is of paramount importance. Moreover, in robotic manipulators, considerable attention is paid to ensuring accurate controls in the detection and tracking of objects.

In particular, in order to make robots flexible, automated object detection facilitated more generalized and adaptive behavior for different objects and positions. This has increased the utility of robotics in industry and allowed the development of complex trajectories for different types of facilities. Consequently, considerable attention was paid to the development of control systems for robotic manipulators with artificial intelligence elements based on technical vision systems. There are two important approaches in artificial intelligence theory used for modelling, such as fuzzy models and neural networks [4].

Based on methods of fuzzy model, fuzzy set and relationship theories are now widely used in modeling control and recognition systems [5], that is, where it is necessary to assess the situation and make a decision under conditions of inaccurate information or in the presence of unclear objectives and restrictions [6]. Also widely Adaptation of machine learning methods using effective technical vision software structures is common. Moreover, neural networks and deep learning techniques are also becoming increasingly popular, but care must be taken to explain and generalize such models. Examples of the use of artificial intelligence techniques based on technical vision systems are in complex parallel manipulator problems that have limited useful workspace areas, poor mobility, and design difficulties. Through decisions, based on the fundamentals of the theory of artificial vision systems possess a significant improvement in the efficiency and performance of manipulators through the use of hybrid and network elements with simple methods of training and adjustment.

### 1. Manipulator classification

Manipulators can be classified according to various criteria, such as mechanical structure, design, number of degrees of freedom, drive type, etc. As shown in Figure 1, manipulators (industrial robots) by mechanical structure are divided into robots-manipulators with flexible structure and mechanical manipulators with rigid structure.

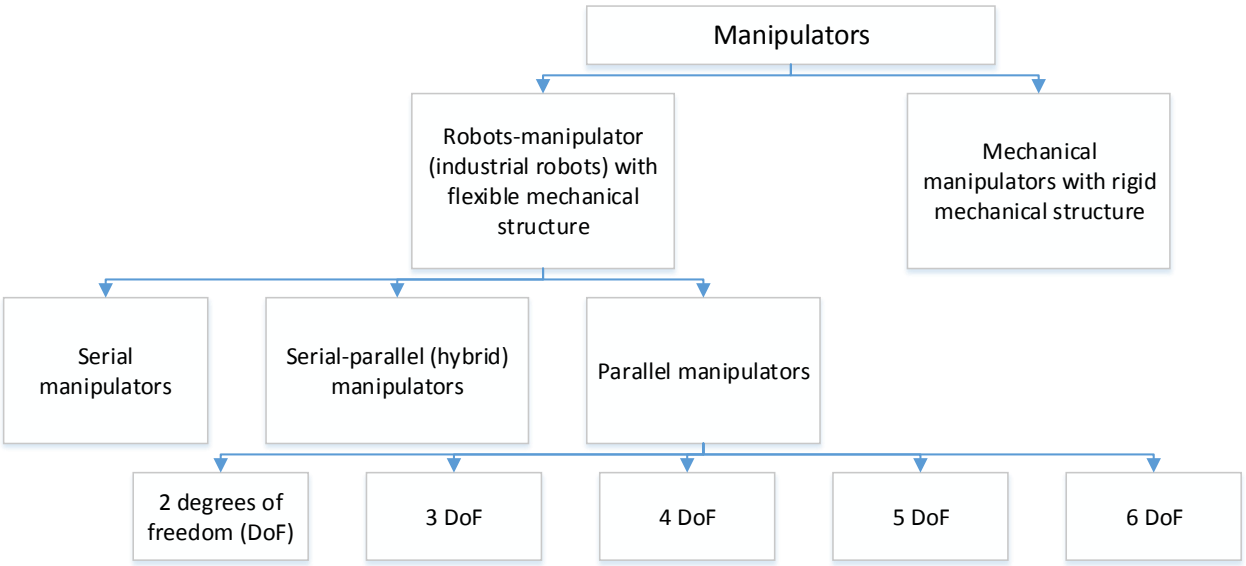



**FIGURE 1.** Classification of manipulators

The past few years have seen important changes in the use of industrial robots, largely due to their flexibility. Flexible manipulator systems from rigid manipulators are characterized by power consumption, lowest inertia, payload to weight ratio and manipulation speed [7], and long response periods and small speed of movement [8]. However, the mechanical architecture of the most common robots is poorly adapted to certain tasks. Therefore, other types of architectures have recently been developed for industrial use, including parallel manipulators [9].

The design classification of industrial robotic manipulators includes such types as serial (serial) manipulators, parallel manipulators and series-parallel (hybrid) manipulators. Serial manipulators consist of series connected links, each of which can rotate about its own axis.

Parallel manipulators have several parallel links that move simultaneously. Parallel manipulator robots have better repeatability than sequential robots [10, 6]. In addition, parallel robots have three main parallel robots have a lower inertia advantage: first, the error is averaged, not accumulated. Secondly, to the movement, as the drives are fixed, and as a result, they are faster. Third, their designs are more rigid as the load is distributed among a large number of links. Although the disadvantages of parallel robots are less space and less needболее сложного анализа особенностей, чем у sequential robots, they turned out to be the preferred candidates for high-speed and high-precision tasks.

The work [11] describes the type traffic characteristics that change after passing certain positions called bifurcation points. Bifurcation-parallel mechanisms combine variable degrees of freedom with high load capacity and accuracy of parallel mechanisms, which makes them a subject of interest for research in the field of mechanics and robotics.

Hybrid manipulators combine the advantages of serial and parallel manipulators. The works [12, 13] pay special attention to hybrid manipulators with series-parallel structure. This type of manipulator is characterized by the advantages of a higher ratio of stiffness to weight and higher carrying capacity, and have significant prospects of application industry. The main component of the hybrid manipulator is its parallel mechanism. As a study, two industrial robots are presented, one with the ability to carry and capture, and the other with the ability to handle complex spatial surfaces.

The manipulator classification by type of drive includes pneumatic, hydraulic, electric and hybrid actuators. Pneumatic and hydraulic manipulators use compressed air or liquid to drive the links, and electrical manipulators use an electric motor. Hybrid manipulators combine several types of drives.

Manipulators can also be classified by functional purpose, for example, manipulators for robotic manipulators in industry, medical manipulators, manipulators for service of space objects, etc.

Currently, the development of algorithms to control robotic manipulators with the use of parallel kinematic schemes is an actual problem in dynamic manipulation problems. Parallel mechanisms are applied in different areas due to a number of advantages over manipulators with serial circuit. Article [14] describes several parallel mechanisms with different quantities and types of degrees of freedom that can be used in parallel kinematic machines, motion simulators and industrial robots. One of the important criteria of the classification of parallel manipulators is the number of degrees of freedom, that is, the number of independent movements which can be performed by a manipulator. There are parallel manipulators with two to six degrees of freedom [16]. The parallel manipulator, which is a closed loop mechanism, usually consists of a movable platform connected to the fixed base by several extremities [9]. Typically, the number of limbs equals the number of degrees of freedom.

Thus, each limb is controlled by a single drive, and all drives can be installed on or near a fixed base. For this reason, parallel manipulators are sometimes called platform manipulators.

### 1.1 Parallel manipulators with two degrees of freedom (2-DoF)

Article [9] describes a parallel platform with two degrees of freedom (Figure 2). The movement of the platform is achieved by movements of links 3 and 8, transmitted to the platform by two parallelograms. The movable platform has two purely progressive degrees of freedom relative to the base due to the flat four-bar parallelograms. The system has excessive limitations, because only one planar parallelogram with four rods is required to achieve two degrees of solid freedom in this design. Two four-rod flat parallelograms are used to increase rigidity and symmetry.

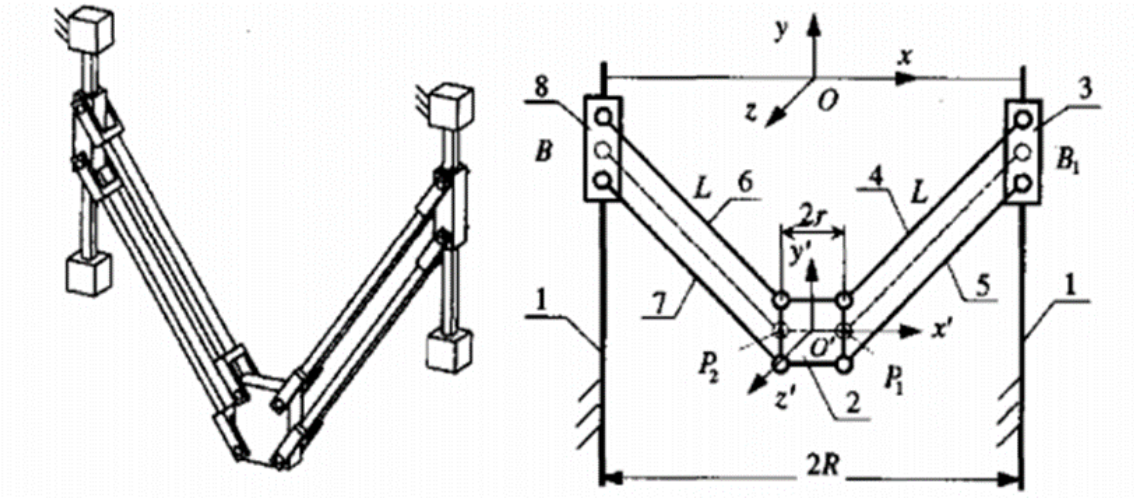



**FIGURE 2.** Parallel platform with two degrees of freedom [9]

### 1.2 Parallel manipulators with three degrees of freedom (3-DoF)

The work [16, 17 and 18] analyses a parallel mechanism (PM) with three degrees of freedom with a centering device as a drive mechanism in Figure 3 [18]. The rigidity model was created on the basis of the virtual operation principle and the kinematic model of the PM, and a quantitative analysis of the development the characteristics of the rigidity depending on the position of the PM. The efficiency of the kinematic model shows that the progressive stiffness decreases when the moving platform axially moves forward, and the rotational stiffness is mainly determined by the position parameters.

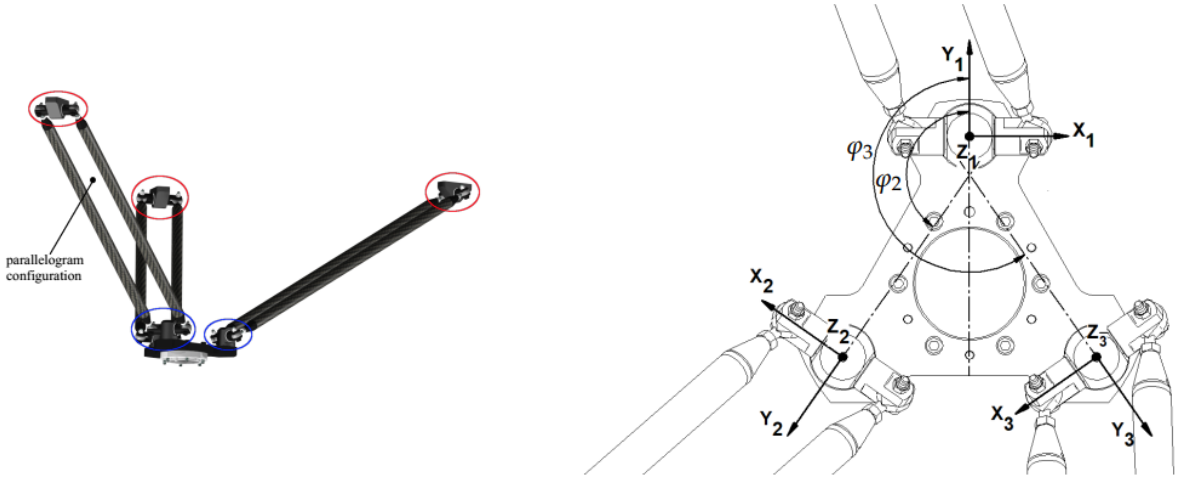



**FIGURE 3.** Parallel mechanism with three degrees of freedom

### 1.3 Parallel manipulators with four and five degrees of freedom (4-DoF and 5-DoF)

A parallel manipulator with 4 and 5 degrees of freedom usually has four or five independently actuated hinges that control the movement of the platform. These compounds may include rotating, prismatic or spherical compounds. However, the work [9] states that Fully parallel manipulators with such degrees of freedom simply do not exist or are used as a hybrid manipulator, i.e. with series-parallel connection.

### 1.4 Parallel manipulators with six degrees of freedom (6-DoF)

Parallel manipulators with six degrees of freedom are the most popular manipulators, examples of which are the Stewart platform, hexapod, etc. Classical parallel manipulator architecture with six degrees of freedom, shown in Figure 4 [9], has been carefully studied in works [9, 1 and 19]. Most parallel manipulators with six degrees of freedom have six retractable limbs, which provides high stiffness, low inertia and high load capacity. However, these manipulators have problems with small useful workspace and design difficulties. In addition, the analysis of their direct kinematics is very complex.

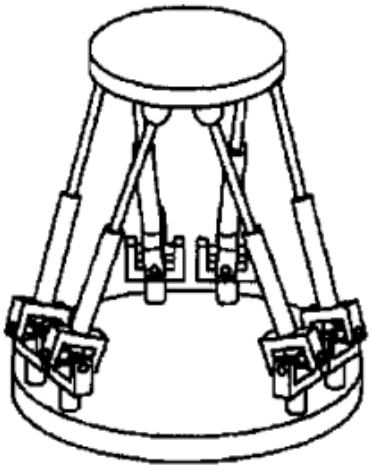


**FIGURE 4.** Parallel mechanism with six degrees of freedom

## II. METHODS

Industrial robots are widely used for repetitive, unmanaged and dangerous tasks [20, 13]. Therefore, improving the efficiency of manufacturing industrial robot manipulators is of paramount importance. This can be achieved by artificial vision and path planning techniques focusing on localization and shortest path calculation. In particular, it is important for production, which widely use robotic manipulators to place/move the object. This is even more difficult when it is necessary to detect soft, brittle or opaque objects, since it is much more difficult for a robot to focus on their indistinguishable features [21, 3]. Proposed robotic structure with artificial vision with 6 degrees of freedom, which with high accuracy discovers objects of interest (using red, green and blue (RGB) markers) as shown in Figure 5 [13]. In particular, the technique of color marking of objects was used to simplify and construct correspondence between the stereo camera system. Robotic vision includes advanced techniques and algorithms for both computer vision and machine learning [3]. This mainly facilitates The kinematics of the robot are measured and calibrated by the eye sensor, which affects the robot's physical and environmental performance. What was then used was an object placement method, called a transform, which generates data points to place an object in real time. Pilot results show that the proposed structure can effectively enhance accuracy of path planning and improve the detection of objects by means of stereovision robots.

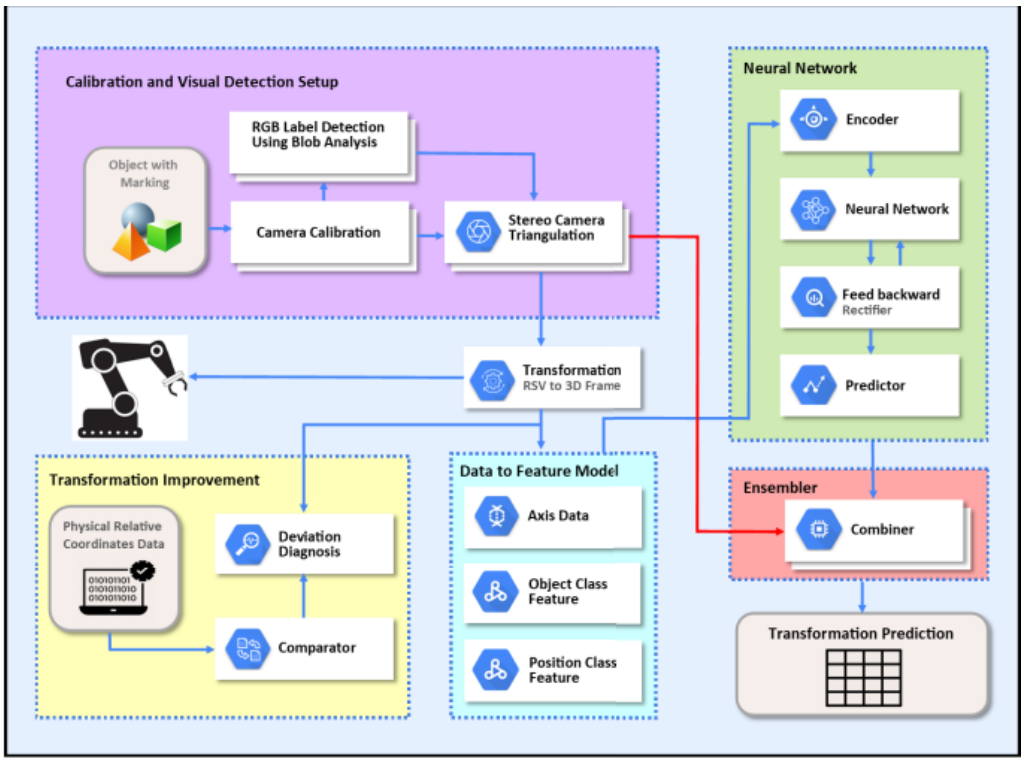



**FIGURE 5**. Robotic manipulator platform with stereovision for object detection and tracking

Parallel manipulators are always presented as having very good characteristics in terms of accuracy, stiffness and ability to manipulate large loads. Unfortunately, this robot always faces many complex uncertainties and external disturbances caused by unknown dynamic systems, external noise and non-linear friction forces. Thus, the development of a trajectory control system for parallel manipulators poses unique challenges, especially when high-speed motion, high accuracy and high acceleration are required.

Parallel mechanisms can move in different directions simultaneously, which can eliminate vibrations with several degrees of freedom. The classic parallel mechanism and Stewart mechanism have such characteristics as high rigidity, high load capacity, small workspace and high control accuracy [5, 22]. In recent decades has been proposed A variety of vibration absorption techniques based on the Stewart mechanism. While Stewart's platform offers unique advantages over traditional vibration control designs, Stewart's platform's kinematic and dynamic analysis is complex. The main problem with Stewart's common platform is that movements on different axes are strongly connected, which means that movement in any Cartesian direction causes movement of each reattached leg of the seat platform, resulting in mathematical complexity of the control system design [3, 23]. To solve this problem, the Stewart platform, called the Stewart cube platform, was first proposed by Geng et al. as a six-axis insulation system architecture. The structure of this configuration is shown in Figure 6 [5]. This figure shows the principle построения конфигурации куба. На основе куба две диагонали удаляются плоскостью ABC и плоскостью DEF. Две the plane after removal is called the load plane and the base of the cubic Stewart platform, and the six side lengths of the cube, AF, AE, BF, BD, CE and CD, become the six supports of the cubic Stewart platform.

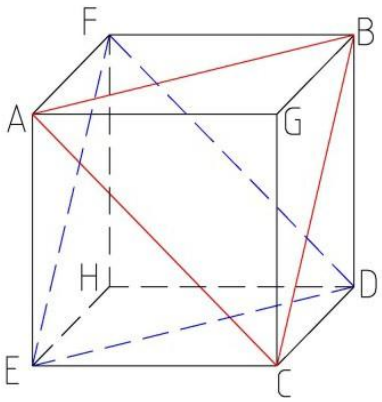



**FIGURE 6.** Stuart Cube Platform

Dobriborsch and Koljubin developed Stewart's robotic platform with two degrees of freedom using technical vision. Functional and kinematic diagrams of the developed robotic complex, which consists of a rectangular shaped platform, regulated by two servos mounted on the base, are also presented. Developed Mathematical simulation of adaptive control on stabilization of an object in given coordinates with the application of a number of assumptions: the force of friction and sliding is not taken into account, the object is homogeneous and is always in contact with the platform surface. On the basis of the developed robotic complex an experimental approbation of adaptive control of parallel kinematics robot-manipulator designed to solve problems of dynamic manipulation of object, in particular in tasks of capture and movement of object.

The literature suggests different approaches to parallel tracing mechanisms such as PID [7], adaptive management [14], Reverse control [19], optimal control [22], sliding control [14], and new speed-based control with Camera Space Manipulation (CSM) [5, 24]. The proposed control (Figure 7) has the ability to manipulate static and moving targets even when the trajectory of the target motion is not known in advance, unlike the CSM, originally designed to manipulate only static targets.

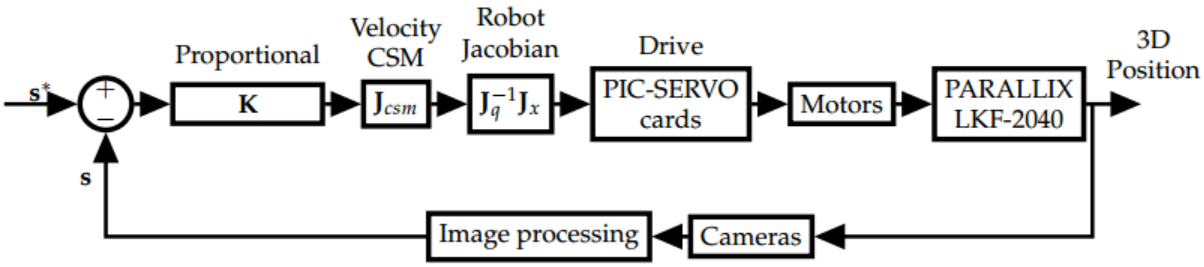



**FIGURE 7.** Speed-based control block diagram Camera Space Manipulation [5]

Among them, robust management techniques are used to address complex uncertainties and external disturbances, and to achieve higher robustness. Also, when working with parallel mechanisms was widely investigated with the development of a six-freedom gripper [1], the robot can capture a target from different angles and locations in a three-dimensional area. Analytical methods were used to analyze the geometric structure of 3D data, and thus it was possible to find the best points according to different captures.

For mathematical constraint analysis and motion of spatial parallel mechanisms (PM) [25] is widely used by the inverse product method based on screw theory, which contains information on position and orientation. Theory facilitate the synthesis of the PM, which is carried out on the basis of the sequential and rotational movement of the torque, as well as the force and torque. Because the final screw is used to describe the final movement of the mechanism instead of the instantaneous movement, unlike the instant screw synthesis method, the final screw method eliminates the need to determine. Whether the synthesized mechanism is only instantaneous or not. And the studied mechanism is characterized by variable/fixed axes. Therefore, the movement of the mechanism can be fully and precisely described by a finite screw containing information about the change of the rotation axis in time. To get the standard finite screw limb shape, by end of final screw Moving platform factors are added in a linearly independent rotational and progressive factors. And then, by replacing the joints and changing the position of the joints in the standard form of the extremity, by careful analysis, possible derivatives of the extremities can be obtained. By means of a strict mathematical inference, the method is able to ensure the correctness of the resulting response chain. Then the parallel mechanism with variable/constant rotation axes according to the assembly requirements between branches [11].

Since parallel robots are used in different areas, the purpose of parallel robots differs, which can be easily done from the previously mentioned applications, given that one requires high speed and the other requires high precision [26]. This prompted research to optimize the parallel robot. One of the important components of optimization is that there is no perfect optimization of each aspect, optimization for one or more purposes is practical and reasonable. Each researcher had many purpose functions. One of the most classic targets was called dexterity, which was derived from the Jacobi matrix. Another known target, called manipulation. Kinematic optimization is one of the most important and complex problems in the field of parallel mechanisms related to productivity assessment and dimensional synthesis. To obtain the working space of each limb of the parallel manipulator can be used conventional methods [1] if the kinematic chain The extremities have a consistent architecture. Each kinematic circuit consists of a sequence of rigid links connected by hinges such as rotational (R), prismatic (P), universal (U) and spherical (S) hinges.

However, the general algebraic method of defining the parallel manipulator space has not yet been determined, despite its advantages, provided by precise algebraic formulation of the working space boundaries of the achievable position and effective computing, for which only the kinematic architecture of the mechanism is required. In [27], the paper proposes a systematic approach to estimating the working space of parallel mechanisms using a geometric method that defines the boundary of the working space of each link, if viewed as an isolated kinematic chain, and then gets the common workspace as the intersection of the volumes of the workspace of the limbs. The method is

supported by a numerical example that compares the proposed method with a discrete one, emphasizing the effectiveness of the proposed algebraic formulation in achieving the same result. Moreover, compared with previous methods, the proposed wording does not require prior knowledge of kinematics the robot, but only the structure of the analyzed mechanism. Thus, the proposed method is suitable for procedures in which the working area of the class of mechanisms is calculated repeatedly, such as optimization algorithms, due to the short calculation time and preliminary analysis of the working area of complex mechanisms without the need for a complete kinematic model. On account Both aspects in future developments, the proposed method may be a feasible and more effective alternative to traditional methods.

## III. RESULTS

Parallel manipulator research techniques offer a number of results that can be useful in various fields. Some of the possible modelling results include [9]:

- description of the kinematic properties of parallel manipulators, such as the angles of rotation and movement of links, which can be useful for the development of control algorithms and path planning;
- analysis of the dynamic properties of parallel manipulators, such as forces, moments and acceleration, which can be useful for determining the maximum load capacity of the manipulator and optimizing its performance;
- development and optimization of control algorithms that allow parallel manipulators to perform tasks with high precision and speed;
- research of structural properties of parallel manipulators, such as rigidity and stability, which can be useful for the development of more reliable and safe designs of manipulators;
- assessment of the performance and efficiency of different parallel manipulator designs, which can be useful for choosing the most suitable design depending on the task to be performed.

## IV. DISCUSSION

Dynamic manipulation tasks such as tilt, shock, throw, and pushing, etc. Optimal motion control involves the use of algorithms to calculate the most efficient and accurate trajectory that the robot's manipulator should follow. This may include taking into account factors such as the weight of the payload carried, the speed and acceleration of the manipulator, as well as the position of obstacles in the environment of the robot [16].

By combining artificial vision with optimal motion control techniques, the accuracy and efficiency of the parallel manipulator can be improved. For example, machine vision can be used to determine the position of the operating unit and provide feedback to the controller, allowing it to adjust real-time trajectory to compensate for any errors.

In general, parallel robot methods are an efficient solution for performing tasks with high precision and carrying capacity in confined spaces. However, before using parallel robots it is necessary to consider their limitations and choose a suitable design depending on the requirements of the task.

## CONCLUSION

Summing up the results of the analysis, I think that a promising direction of the study is to solve the problems of trajectory, trajectory planning and identification of the contact model between the object and the platform surface.

The main contribution of all articles lies in the processes of withdrawal from configurations robots, obtained by synthesizing types, in the structure of robots with a certain required movement. Theoretical applications from type synthesis to hybrid manipulators are more useful for obtaining new industrial robots with characteristics of simple structures and high degree of modularity. This article provides a comparative analysis of existing works on manipulators with artificial vision in different configurations. The theoretical and practical significance of the study lies in the fact that this overview article will be the basis for the further development of parallel manipulator with elements of artificial vision and the development of a theoretical basis in this direction.

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