Research and Application of Industrial Robot Manipulators in Vehicle and Automotive Engineering, a Survey

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Abstract. The tendency of the manufacturers to lower costs, accurate work, and fast production rates force them to look for extraordinary ways like using robots instead of humans in an industry which meets their requirements. One of the most important operations in vehicle industry is welding. This operation requires proficient workers and it is time consuming as well as fallible. The application of robots can increase the productivity and the quality in this area. Other fields like painting, material handling also can have benefit from the application of robots. This work is going to review the usage of robot manipulators and their different applications in the automotive and vehicle industry and the relationship between the applications and the optimized robot manipulators also a review was made about robots' statistics worldwide.

Keywords: Robotics · Optimization · Robot application · Industrial robots

1 Introduction

Nowadays robots are playing a great role in all aspects of human life [1–3] because of the human tendency to fulfil his needs with low cost, high quality and fast production rates, which may be difficult just by workers as well as these robots is preferred especially in some risky working environments, which should undergo for a serious risk assessment [4–6]. Vehicle industry and other automotive engineering are a perfect area being robotized for the above-mentioned reasons. Axiomatically robots' specifications depend on their applications which differ from purpose to another one like assembly robots [7, 8] which are carried out heavy parts, or PCB manipulators which need to carry dynamic loads, of course both previous examples require precise motion. There are many types of the industrial robots and it is used according to the purpose and desired duty [9, 10]. The most common type of robots is used is serial robot manipulators which are a series of rigid bodies, called links, are joined together by means of joints [11], see Fig. 1.

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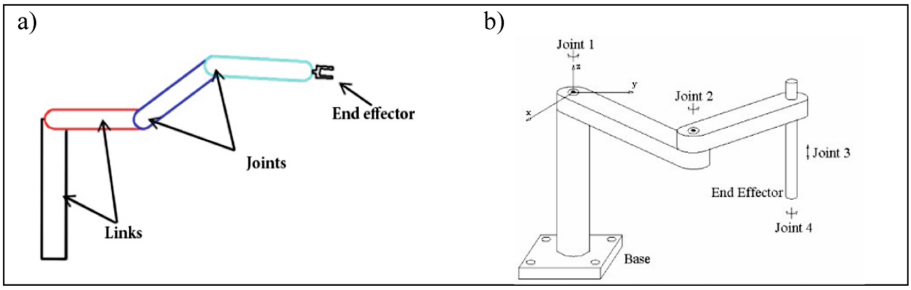


Fig. 1. (a) 5R manipulator, (b) RRdR manipulator (SCARA robot)

In manufacturing lines of the vehicle industry, it is economically undesired to design all the robot manipulators for the same criterion because robot's joints and links are subject to different loads in different lines of production it is clear that robot manipulator in assembly line suffer from more stresses than that one in the painting or welding lines. Therefore, there is a need to optimize manipulators links and joints to reach optimum design [12, 13]. Another fact should be considered about using robot manipulators in automotive industry is that the working area or the configuration space of the manipulators may contain static or dynamic obstacles which leads us to supply the robots with path or trajectory planning. These paths might just a predefined set of points [14] in the Cartesian space in case of a static environment or paths continuously change due to the dynamic environment [15] but in both cases, these sets of points should transform from a configuration space to joints space by means of inverse kinematics [16].

2 Path and Trajectory Planning

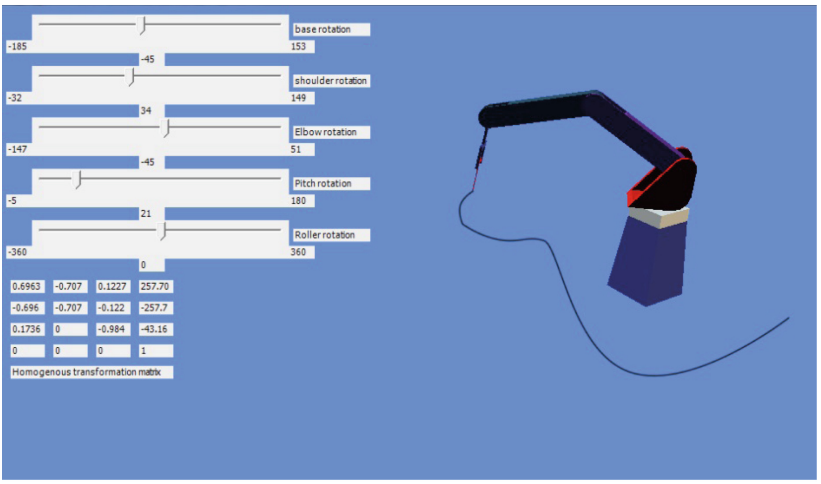
Over the last decades, robot manipulators have received much of the robot community attention due to its wide applications in industry for many tasks.

The most important function in robot motion is to plan its motion to the robot reach point in a shortest path consuming less time consequently, consuming less power for its actuators. The main advantage of planning is that it enables a robot to achieve complex goals [17]. For a robot to move from one configuration to another in a cluttered environment. Path planning is just a geometric operation to describe the path of motion for a robot, but doesn't describe how the motion happens. Path planning for articulated robotic manipulators is usually more challenging than for mobile robots because of the high-degrees of freedom. The main key in using a robot manipulator in different industrial application is that for each application an appropriate trajectory planning should be occurred where the trajectory describes the motion on a path regarding the velocity, force and acceleration [7, 18, 19].

In brief, for any industrial robot manipulator application, there is a path consists of a set of points in a space, each point has been represented by a 3×1 position vector and 3×3 orientation matrix, the vector and the orientation matrix were being concatenated in a single 4×4 homogenous transformation matrix [9]. Figures 2 and 3 illustrate different points on a single path.

$$\begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, \begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix} \Rightarrow \begin{bmatrix} r_{11} & r_{12} & r_{13} & p_x \\ r_{21} & r_{22} & r_{23} & p_y \\ r_{31} & r_{32} & r_{33} & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

a)



b)

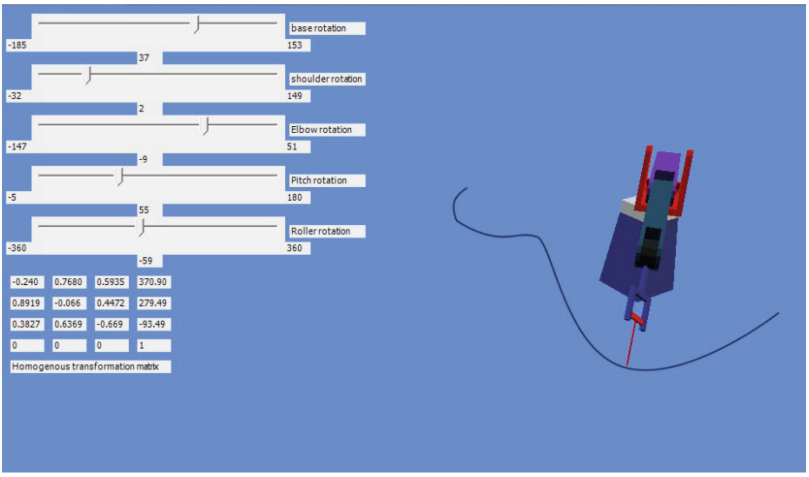


Fig. 2. (a) and (b) Different robot configurations at different points on a path

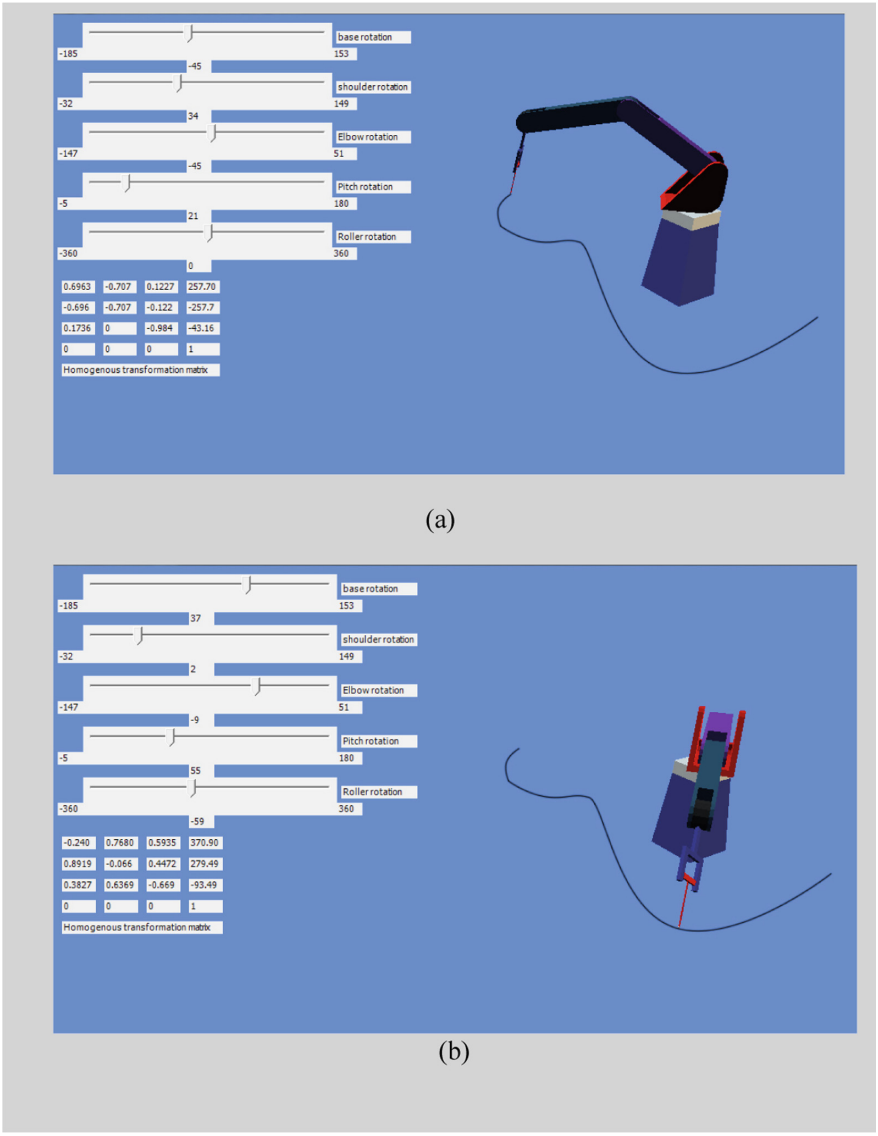


Fig. 3. (a) and (b) Different robot configurations on different points on a path

For a trajectory extra description is needed for the path rather than just series of single points as mentioned before for each point on the path we must specify the velocity, acceleration and force which they are mapped from the joints space of the robot.

3 Optimization

In this section we will try to answer the question what is the relationship between optimization technique and robot application? In brief, optimization is a search for local minima and/or maxima at a specific domain in a function [20]. In the previous section it has been mentioned that the key point of using a specific robot manipulator in different industrial application is using a well-defined trajectory this is not an easy operation if you take consider that each path connecting the start and goal points for the robot may have hundreds of intermediate points furthermore, there are an infinite number of expected paths reach the start in goal points the problem may be more complicated if the velocity, accelerations and force needed to be described for each point on the trajectory. The development of computer science and invention many heuristic and biologically inspired algorithms make it easier to optimize the above mentioned infinite expected trajectories to a single optimum one, hence for a given industrial application optimization techniques can suggest the proper trajectory that should be followed.

Also, optimization methods were used in design engineering components by setting a mathematical model for the problem and search for maximum load or minimum thickness and many criteria were put like reducing airplane weight or cost consideration [21].

Researchers have been using many optimization algorithms for decades in many scientific fields [22], an example of these algorithms is *A* star, ant colony, bee, genetic, artificial neural network, particle swam object, harmony search and may others as well as hybrid of two or more algorithms was introduced in the optimization process. The purpose of finding the optimal solution for a trajectory is to minimize the consuming time and power i.e. optimization can be considered environmentally friendly process as well as it increases the life time of the robots which is economically desired.

4 Robot Manipulators in Vehicle Industry

Many of the mechanical operations occurs to produce the final shape of the vehicle these operations are casting, cutting, welding, assembling and painting the order of these operations might differ slightly but it doesn't matter. So, in this section we are going to explain some of the concepts of these operations.

4.1 Casting

Casting is the process of forming products through melting engineering materials and pouring it in preformatted spaces called moulds. In this field robots may use in die formation by 3D printing or drilling a block of the material die also robot manipulators in the transmitting process from the furnace to the die which is much safer than doing it by workers.

4.2 Grinding and Polishing

Robots have used to finish the casted products accurately as well as removing unwanted edges and polishing the final product, obviously this work requires expert workers and more time compared with robots which they make the process just a systematic operation. Grinding robots have used in different fields to many extents, it was used to grind submersible structures like dam gates including calculating the material removal rates [23] and hydro turbine repairing and manufacturing [24]. Material removing rate [25] is the most important function in this operation which is preferred to be robotized not just for economical purposes, but also for safety, especially in dangerous places like nuclear power plant, where grinding robot manipulator has been used for grinding the pipeline system of the plant [26]. Grinding robots usually have a grinding stone attached to the end-effector, but robotic belt grinding [27] also have used to increase the productivity and to grind the more complex surfaces. Some studies have focused on the temperature generation and distribution due to grinding process [28], which are important for crystal structures properties prediction at some temperature degree at the grinded area.

Polishing process give the final fine and shiny appearance to the surfaces and polishing robots [29, 30] widely used in different industries like polishing marvel, granite metal sheets etc. and some studies have used different techniques for polishing process like machine vision [31] and sensor monitoring [32].

4.3 Cutting

Manufacturers have been using cutting machines for many years to split parts away. In the case of using 3 axes, or more, CNC or robot manipulators, different complicated shapes can be given. Cutting robot manipulators have huge applications in different fields of the automotive industries like butchery automation [33]. Cutting Serial robots have the challenge of low stiffness [34] in aerospace or vehicle industries, where cutting forces and gravity result in positioning errors, but some works have overcome this problem by introducing an approach to optimize positioning of the tooltip [35–37]. Recent techniques have used damping control system on the cutting tool machine which have given more refine to the cutting streams [38].

4.4 Assembly

It is the operation of gathering different parts together to produce a single complicated system like a car engine or the entire car and it usually tedious and time consuming which makes robot manipulators the right alternative. The classical approach for the robotized assembly operation is the graphically motion planning, though other strategies have been used like machine vision based methods [39] also assembly robots can be equipped with sensors and well-programmed to be safe to work in a cooperative cell with human [40] also collaboration between human and robot [41, 42] have used because it is very handy for this operation. Assembly among all the above-mentioned processes need a special care because this process includes gathering parts of the vehicle together which they may have high weights i.e. more stresses applied on the links and joints of

the robot manipulators therefore these loads as well as cyclic load or fatigue should be considered when the manipulators are designed. Many works have distinguished trajectory planning for assembly process [43] and the trade-off between speed and quality.

4.5 Painting

Painting robot trajectory optimization has done using the offline experimental algorithm by assuming there are no singularities and redundancy [44]. Sometimes painting is not just covering a piece of material with a uniform coating layer it may take the form of art like Chinese painting this operation was robotized by decomposing the painting to separate parts and for each part a trajectory was generated [45] this is useful especially for automobile industry where there is sometimes a need to print some logos or arts on the body.

4.6 Welding

It is a big story where the specifications of the welding or strength of the welded area depends on many factors evolve speed of the solder moving along the desired path i.e. rate of quantity of the solder has been thrown per unit area and the distance between the surface and solder as well as the shape of the solder movement along welding path this is e.g. zigzag, circular and so on. The factors mentioned before makes welding by preprogramed robot manipulators are the best choice [46]. A hybrid algorithm of ant colony and genetic algorithm [47] were applied in path planning for a welding robot where the ant colony system gets benefit from the fast convergence of the genetic algorithm as well as the local optimization has been jumped out due to the mutation of GA. Also, the same hybrid algorithm was used in job scheduling for welding robot [48].

The parameters of welding resistance were optimized to build a relation model that needs least number of experiments for welding production [49] this have done by a combination of orthogonal test with artificial neural network. Another welding parameter optimization have done by response surface, genetic algorithm and neural network [50]. Welding robots have developed to be more handy and productive in different ways like using Speech recognition [51] to control robot manipulators in preoperational setups welding application. One of the simulation dynamic software packages is RecurDyn which can be used to simulate welding robots and return several information like motors specifications or gravity balancing [52].

A hybrid discrete PSO algorithm was introduced to improve production efficiency of the welding robots by improving the path planning of these robots [53].

A mobile welding robot with two optimization models for motion planning problem was introduced and have given the solution for “complex all-position welding operation” [54]. In some manufacturing cases an industrial robot must do multiple tasks for example welding different seams and these tasks occur repeatedly, there are a method [55] to improve the production time of the sequential tasks in production domains in the tasks with freedom of execution.

In most industrial robot manipulators there is the problem of vibration which may be originate form robot motors or due to the dynamic movements. The combination of

minimum-jerk and minimum-distance trajectories lead to an effective kinematic scheme [56]. Two cooperative manipulators in welding process were emulating and investigated theoretically and experimentally [57], the emulating process considered a trajectory planning for the two robots where the genetic algorithm adapted to solve this planning.

5 Optimization and Robot Design

Up to this point the before mentioned text has demonstrated that the optimization of robot path and trajectory is the mutual key among different industrial robot applications in this section the relationship between the application and the robot itself will be answered. First of all robot designers have been seeking for an appropriate robot for the proper application to meet the user economical desires, especially those users in the automotive industry because this industry needs multiple robot purposes or sometimes one single robot for many applications. Thus, for this point many researchers have worked for many years ago for using optimization methods to design the appropriate robot for the appropriate application. Recently topology optimization has been used to design robots [58–60], algorithms like non-linear Levenberg-Marquardt [12] has been used to get optimum links length to reduce error in the position and orientation of the end-effector. These examples and many others illustrate how to apply optimization techniques to design the robot itself.

6 Statistics

Industrial robots are spreading rapidly worldwide as a result of the competition among manufacturers in different countries and reliable statistics refer to the fast growth of robots in the last few years. World robotics report released by the international federation of robotics IFR [61] have shown how numbers of industrial robots have increased during

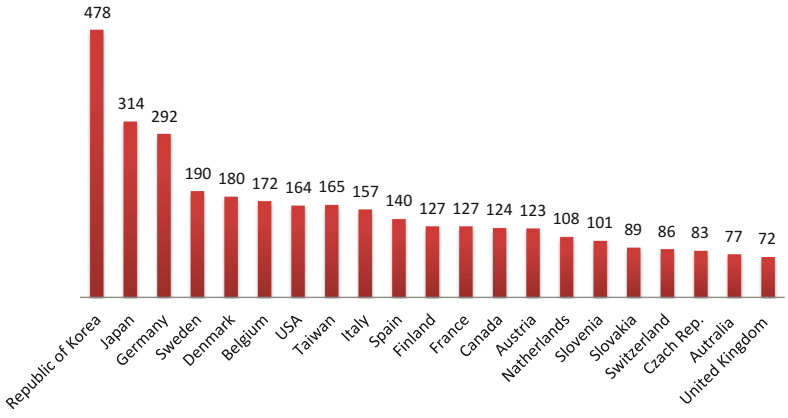


Fig. 4. Number of multipurpose industrial robots (all types) per 10,000 employees in the manufacturing industry 2014

one year see Figs. 4 and 5. Records 2016 for North American Robot Orders and Shipments [62] the hottest Applications and Industries orders for robots have increased by 61% in the field of assembly and 24% in spot welding also consumer goods and food industry have increased orders for robots by 32%. Figure 6 shows how robotics units increased worldwide in the last few years [63]. Anyway, many reports [64] have been done to show the worldwide booming of the industrial robots.

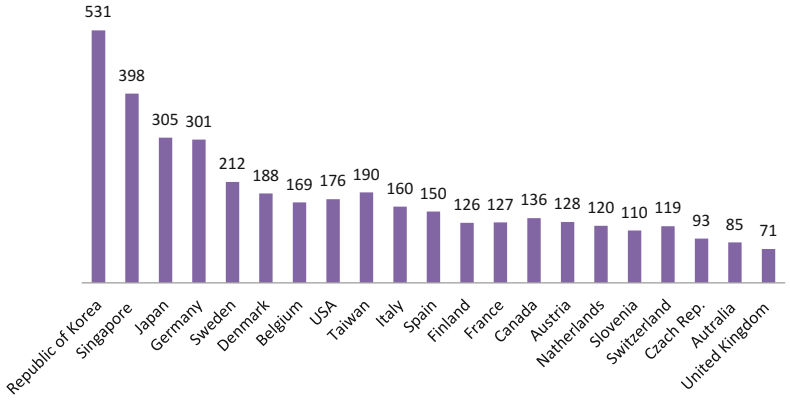


Fig. 5. Number of multipurpose industrial robots (all types) per 10,000 employees in the manufacturing industry 2015

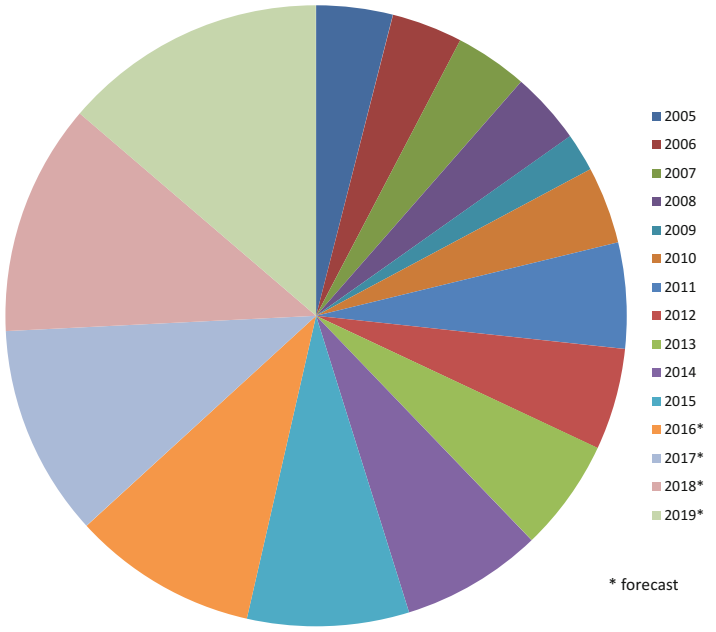


Fig. 6. Annual supply for industrial robots worldwide

7 Conclusion

In this paper we have made a survey on the application of robots in the car industry. The tendency of the manufacturers to lower costs, accurate work, and fast production rates force them to use robots. One of the most important application of robots in vehicle industry is welding. Using robots at this operation results in time saving and better accuracy. The application of robots can increase the productivity and the quality at all manufacturing technologies in this area like painting, material handling also can have benefit from the application of robots. This work is reviewed not only the usage of robot manipulators and their different applications in the automotive and vehicle industry, but the relationship between the applications and the optimized robot manipulators as well.

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