

The Review of Development, Application and Optimal Design of Robotic Arms

Bodong Zhang

College of Engineering, University of Edinburgh, Edinburgh, UK

Email: s2662756@ed.ac.uk

Abstract. Robotic arms can be regarded as the mimicry of human arms without complicated perception abilities but with higher efficiency and safety index. They are pragmatic with appropriate design. Due to the fast pace of the development of technology, robotic arms have become highly demanding in many fields such as factories, airports and even supermarkets. However, most of the work crowds on industrial robotic arms associated with AI system and technology, which is one of the popular trending research motives today. This paper covers the development of robotics arms, some concerned and involved applications such as a safe robot arm system for medication and several optimal designs such as a multi-objective design of industrial robotic arms. The discussion section also comprises some robotic challenges that the world is confronting. By generalizing several pieces of information and ideas, this paper aims to supply some insight into a more effective and eloquent robotic arm frame.

Keywords: Robotic arms, development, applications, optimal design.

1. Introduction

From 2015 to 2020, the average annual installation of industrial robots increased by 9% each year[1], With the high demand for robots, some mobile robots have been applied in massive areas including dangerous conditions like military missions and delicate environment like offices[2], This is a huge innovation and revolution of robotic technology that does not only avoid excessive labor but also reduces expenditure after the third industrial revolution[3]. Several optimal designs comprising a multi-objective design, a Robust Fault Tolerant Optimal Predictive Control of Hybrid Actuators with Time-Varying Delay for Industrial Robot Arm and a design optimization of industrial robot arm to minimize redundant weight. The paper also includes a brief history of how early modern robotic arms were brought into industrial fields as a background. While the discussion part predominantly focuses on the advantages and disadvantages of robots, aiming to provide some critical thinking on how to use them in an appropriate way.

2. Literature Review

2.1 Early Modern Robotic Arms to Industry

Unimation (from Devol's Universal Automation robot) is the first robotics company funded by Engelberger, aiming to sell their two-ton robotic arm, the unimate. It finally sold 8500 Unimates. In 1966, Kawasaki bought the license to manufacture industrial robot arms from Unimation. After that, the competition started rapidly, several competitors appeared such as the Cincinnati-based Milacron. In 1967, Japan imported Versatran industrial robot, which was brought out by AMF Hermatool and made commercially available in 1963. Then, the application of microelectronics and the potential of these robotic arms became popular in the whole host of academic centers. An electrically powered articulated arm that could move through six axes is called the Stanford arm, which was developed by a Stanford Research Institute investigator, Victor Scheinman. With the development, robotic arms can confront more complicated missions. Due to that, more technologies have been applied to industrial fields. Marvin Minsky, from MIT, built a robotic arm for the office of Naval Research for underwater exploration. To ensure accuracy, twelve single-degree-of-freedom joints were utilized to actuate this electro-hydraulic high-dexterity arm. Scheinman continued his work on robotic arms and,

with backing from General Motors, Unimation developed Scheinman's technology into a Programmable Universal Machine for Assembly (PUMA)[4].

2.2 The Development of Industrial Robotic Arms

Industrial robotic arms are regarded as industrial features and manipulator imitated that human arms are called articulated arms, in which all joints are rolling. Nevertheless, the motion of the human arms is not the same as the motion of the articulated robotic arms. Despite that robotic joints have less degree of freedom; they can move with a larger angle. For instance, the elbow of the human arm can only bend in one orientation in terms of the straight arm position, but an articulated robot can bend up or down. An industrial robot arm is called a WAM arm, which is the only commercially free robotic arm with direct-drive ability supported by obvious dynamics between the joints and motors. Furthermore, it is an extremely agile-back drive manipulator with ensured stability. Due to the brushless motor are used in all axes in WAM arm, the spherical workplace's diameter is approximately 2 meters and AC and DC operation can be applied[5].

2.3 Applications for Robotic Arms

Applications for robotic arms are widespread in many areas such as industry, medication and military. However, they can be mainly divided into two applications, the assembly and non-assembly one. The former one is usually smaller with electrical drive while the latter one tends to do welding, material handling and machine loading and unloading. Besides, there is an increasing number of usages of robotic arms in laboratories due to their good ability to take heavy objects and do repetitive missions. For example, they can place the tubes into measuring instruments, lightening the laboratory technician of much dreary work. Three merits are often claimed by manufacturers: improved efficiency, enhanced quality and diffused exposure of harmful chemicals from humans[5].

3. Existing System

Studies on Wi-Fi-controlled robotic arms emphasize the merits of remote monitoring and control capabilities facilitated by Node MCU ESP8266 modules, which improve flexibility and accessibility in industrial operations. Furthermore, the analysis shed light on the selection criteria performed by servo motor based on torque, speed and efficiency, which is important to enhance the function of robotic arms. Research of algorithm optimization and sensor integration concentrates on utilizing control algorithms and optimizing feedback mechanisms for smoother track locomotion and enhanced performance in industrial robotic applications[6].

3.1 A Safe Robotic Arm for Medication

A system that was designed in 1997 and can be applied to prevent cardiovascular disease is called Hippocrate. Regularly, Hippocrate exists in a 6-dof robot arm, a dedicated controller, a control desk, and a DMS pedal. The control desk consists of a keyboard, two emergency buttons, a restart button and a teach pendant for the learning phase. The controller is included in cantilever support, which is installed on wheels and then can be moved within the hospital. Each sub-part of system is separated into several functional blocks, and all possible failures are implemented to set up their results on the whole system with three levels of danger via a systematic study. (Level 1: Patient's or Operator's Death, Level 2: Patient's or Operator's Injury, Level 3: Patient's or Operator's Troubles). The system aims to be an active mechanism, with at least six degrees of freedom, providing force control. According to the experiment results, Hippocrate can assist in producing high quality and complete images of small areas of organisms and ensuring a force control accuracy (better than 0.1N) with a user-friendly graphical interface. Therefore, it is suitable when detecting cardio-vascular diseases on a regular basis where short-term repeatability and high accuracy are required. However, because of the low-speed measurement (maximum 10cm/s) and long respond time of switching off the power

(10ms in the worst case), it should not be used in emergency medical situations such as acute appendicitis and severe distal radius fractures [7].

3.2 Wireless Mobile Robotic Arm

The methodology of this optimal design contains mechanical and electrical design, software development Arduino Mega 2560 and Sony Play Station 2 (PS2) wireless controller. To make this project reliable, hardware and software functions are integrated. The Arduino Mega will be the interfacing for the robot and controller PS2 wireless will manipulate the movement of the robot. By using PS2 controller, it can achieve movement, picking and placing the object in a precise and user-friendly way[8].

4. Optimal Designs of Robotic Arms

4.1 A multi-optimal Design of Robotic Arm

Various loads and capacities of industrial robotic arms have been optimally performed through a multi-objective design, which provides a series of design mechanisms. To reduce the cost of operating and running the arm, the choice of cross-section areas and material of different links is critical. By using stress analysis, the intention of this optimization is to determine the type of material and physical dimensions of the robotic arm to withstand high loads at vulnerable positions. Besides, based on a vibration analysis, material architecture selection is included to avoid robot failure at or close to the frequency of resonance. Therefore, some discoveries are supported by finite element simulations in ANSYS based on several design equations of stress analysis. For instance, the total bending

moment (MT) is calculated by $\sqrt{M_{x\text{direction}}^2 + M_{y\text{direction}}^2}$. While the bending stress due to moment can be expressed as $\sigma = \frac{MT \times Y}{I} + \frac{(\sum F)}{A}$. Where I is the second moment of area and A is the cross-section area. The maximum normal stress criterion and factor of safety (FOS) are expressed as follows: $\sigma_{1,2} = 0.5\sigma \pm \sqrt{(0.5\sigma)^2 + (0.5\tau)^2}$, $FOS_{normal} = S_y \div \sigma_1$, when the shear stress τ equals to 0, and S_y is the yield strength[9].

After figuring out the stress analysis by applying Finite Element Analysis (FEA), a suitable design method is proposed to choose the optimum material. Thus, the research done using ANSYS indicates that Aluminum Alloy ensured high factors of safety (FoS) values, acceptable deflection, and high natural frequencies compared with the other surrogates. Moreover, the results demonstrate that the links taking diameters from 20 to 70 mm can lift mass-loads ranging from 2 to 16 Kg and would result in a presetting desired FoS range of (2 to 6). Learning the patterns of natural frequencies via FEM shows the suggested recommendations to shun working at the resonance frequencies. When contradicting it with Structural Steel based design, this design enhances the FoS by 5.9 % compared with an Aluminum Alloy based design and by 56.9 %. Therefore, same percentage of the operating cost is minimized by this light design. The natural frequencies are monitored to be slightly over 45 Hz, and the robot arm avoids operating close to or at the resonance frequencies. In addition to the body structure of the robot arm, the influence of the reducers and motors on the stiffness and vibration of the robot arm is presented. Lastly, the Genetic Algorithm (GA) is applied to optimize the locomotion of robots without the evaluation of Jacobian matrix, and the joint rotation is treated under literal mode[10]. The exhibited mechanism ascertains the coefficients of a polynomial tracing the angular displacement as a function of time. 5 seconds is obtained to be the optimal path mission time under the minimum consumed power. The result also reveals that jacking the rotational angle leads to an increment of power for a limited span of time. Robo-Analyzer simulations are relevant to acquiring the best alternative solutions for some end-effector positions, which highly minimizes the torque consumption (operating time).

4.2 The Optimal Prediction of Robust Fault Tolerant Control of Hybrid Actuators with Time-Varying Delay

Grounded on error dynamics, the computation of states and a predictive controller, a nonlinear faulty hybrid actuator system based on predictive control via Linear Matrix Inequalities (LMIs) is proposed and implemented via an updated state feedback control law. First, the performance of a robust MPC scheme in which the future control sequence is used to make up the varying time delays. Second, to deal with actuators' faults to effect robust path tracking, an implementation of a robust stable hybrid fault tolerant predictive control. The firmness of hybrid systems on the proposed control scheme is a very sensitive norm. Thus, when under faulty hybrid (electric and pneumatic) actuator, firm conditions are required for manipulating the industrial arm. Based on Lyapunov-Krasovskii (L-K) theory, less conservative stable conditions in terms of LMIs are given and applied to ensure the asymptotically robust firmness of closed-loop constrained system that is dependent on delay-range. In addition, the enhancement of the electric motor is caused by the transformation of the pneumatic pressure to an electric scale, which is also a valid actuator to reach an accurate ultimate position. Moreover, this proposed control strategy for a hybrid robot with n-DOFs is available in various industrial applications such as exoskeleton robots [11].

4.3 An Optimal Design of Industrial Robotic Arms to Minimize Redundant Weight

For industrial robots, the projected cost will rise with the extended reach length and payload. Thus, the choice of motors, especially on the second axis, should be powerful. With higher expected positioning precision, the rigidity of the arm becomes important, since less flexible materials should be utilized. In this case, more motor energy will be consumed for redundant weight, which is unnecessary and ineffective. One of the studies proposed that if the concentrated loads could be diffused by a geometrical change, particularly on the second axis arm, deformation at the tip of the robot will be reduced.

In a common structure, the support is on one side, and the load is on the other side, while the transform of pulling and pushing the rotating force to the axial force rises the strength and reduces the mass. By digging an appropriate channel on the second axis, this study tries to decrease the weight via material deduction. Some features of the study are shown to differentiate this research from others: Firstly, the study attempts to optimize the existing robotic arms rather than designing new ones. Secondly, the motor load is considered to analyze the articulated robot. Thirdly, ANSYS 16.2 Shape Optimization package is used to determine the location of the channel. Last, the weight of the handled material causing the force will not be neglected, which is added to the tip of the robot. The simulation will not degrade the strength of the arm and raise the applied motor load. The result shows that the weight is reduced after changing the shape of the material. Meanwhile, there is no increase in maximum deformation[12].

5. Discussion

Despite that robots are intriguing and promising, diverse conditions on the manufacturing floor, lack of skilled personnel, functional validity and reliability are only part of the challenges but certainly the kernel ones that suppress extensive applicability of smart industrial robots. Customized systems that are oriented to distinct ambient conditions will not be sustainable in intelligent manufacturing[13]. Diverse conditions, for example the lighting conditions, the accuracy of the system can be affected by vast object types and a field of view distance. The adjustment to the variations in the circumstances can require alterations in software or hardware replacement. The adjustment of several components should only have minimal influence or no influence on other components in the system. Thus, the feature of modularity [14] is one of the prerequisites of the smart industrial robot system.

The intention of the robotization and deployment of the industrial robots is to replace works that are jejune and vapid. Similarly, tasks that are under high injuries risk and require low-skilled human dexterity and intelligence will also be altered. More innovative occupation openings are presented

during the process of robotization. Nevertheless, the number of skilled personnel that can manipulate and maintain the advanced technologies of the intelligent industrial robotic system. From 2018 to 2028, the approximation of this skill gap in United States is 2.4 million unfilled positions[15]. The operation behind an intelligent robotic system can be extraordinary complicated even for a career man. The applicability to other customized targets and serviceability should be available without deep insight into the potential object technology.

Under AI-based robotic systems, the capabilities of following the specific instructions and maintaining the level of performance of the robots are the core issues, especially when regulating the system to novel circumstances. When manufacturing, these systems are put into successive and sequential operation, and it can be a mission-critical production circumstance with limited maintenance times. In intelligent industrial robotic systems, this issue is related to a consensus that is regarded as a “reality gap” [16]. Even if some simulations can be achieved under reliable operation, the model is unpredictable when operating in a new circumstance. A more reliable simulation-to-real diversion is required because the maintenance time can be very limited in the real world.

6. Conclusions

From the past inception as rudimentary to the present exquisite, AI-integrated system, the development of robots has scaled to unprecedented heights that reshape the contemporary industrial fields and service sights. This paper recalled this prominent journey by generalizing kernel historical chronologies, distinct applications and several progressive optimal design methodologies. The track of robot arm technology is not only one of the accessorial enhancements but also a testify to a consecutive chase of productivity, accuracy and adaptability.

The historical analysis compartmentalizes a crucial switching from simple, hydraulic-powered arms like the Unimate to highly dexterous, electrically driven systems such as the Stanford Arm and the WAM arm. The advancements in microelectronics and control theory lead the evolution that enable robots to transfer from repetitive tasks to complex set and refined manipulation in fields ranging from manufacturing to medication, as exemplified by the Hippocrate system for cardiovascular imaging. Because of the proliferation applications that indicate a distinct and clear trend towards profession, robotic arms switch from generic tools to being meticulously designed for specific environments and tasks, containing remote operations through wireless controls.

The kernel of headway is the field of optimal design. According to the discussion, multi-objective optimization utilizing FEA tools such as ANSYS is critical for developing arms that are not only powerful and accurate but also lightweight and energy efficient. While materials are diverted to metals like Aluminum Alloy, optimized geometries, and advanced control strategies like Robust Fault Tolerant Predictive Control are crucial in improving performance while minimizing operational expenditure and lightening failure risks. With these design philosophies, robotic arms can be manipulated authentically away from resonant frequencies and maintain precision even under variables loads and potential actuator defaults.

Nevertheless, as the discussion part mentioned, the path of this technical raise is filled with challenges. The “reality gap” between simulation and the reality leads to the obstacle of the pervasive deployment of smart robotic systems, which is a remarkable technical vacancy manpower capable of maintaining these complicated systems, and the demand for better modularity to accommodate diverse and dynamic manufacturing circumstances. These are not only technical barriers but also systemic issues that require cooperative solutions from industry, academia, and government.

In a word, the future of robotic arm technology centers at the intersection of mechanical innovation, advanced materials science, and artificial intelligence. The next cutting-edge technology can bridge reality automatically which will involve generating more intuitive, self-calibrating systems. By highlighting the current challenges and keep up with the design and control, the next generation of robotic arms will exceed their constraints, unlock new possibilities in automation and polish up the edges of human-robot coexistence.

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