Design and Manufacturing of Six Axis Robotic Arm

Mr. Patil B.J.[1], Mr, Panchal J.G.[2], Mr. Karle S.N.[3], Mr.Goyal K.P.[4], Prof.Lakal N.V.[5]
[1, 2, 3, 4, 5]Department of Mechanical Engineering
[1, 2, 3, 4, 5] Sinhgad Institute of Technology, Lonavala,

Abstract*-Six-axis industrial robots are one of the most powerful tools available today. This type of robots performs a wider range of applications with greater flexibility. In their simplest terms they consist of two units; the robotic arm and the control system. This project is to design and manufacture a six axis robotic arm which will be of universal type. It is called as six degrees of freedom or six-axis robot because the arm has six axes which allow it to move to any point within a working envelope. The robotic arm is to design for payload of 10 kg and 1 cubic meter spherical volume. The PLC programming is used for controlling of robotic arm. Electric DC motors are used for actuation of robotic arm. The wrist of the robotic arm can be changed as per the operation to be performed. The arm is designed considering the three applications which are pick and place for pay load upto 10 kg, spray painting and riveting. The project is mainly to be completed in two stages. First stage will be designing of robotic arm and selection of components. Second stage will be Manufacturing and assembly of robotic arm.*

Keywords*-*Robotic arm, automation, six DOF, multipurpose wrist etc.

I. INTRODUCTION

"Robotics is a field concerned with the intelligent connection of perception to action." A Robot is a reprogrammable manipulator designed to move material, parts, or specialized devices through various programmed motions for performing various tasks. The most common manufacturing robot is the robotic arm. A typical robotic arm is made up of seven metal segments, joined by six joints. The computer controls the robot by rotating individual step motors connected to each joint (some larger arms use hydraulics or pneumatics).

A robotic arm is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks. The links of such a manipulator are connected by joints allowing either rotational motion (suchas in an articulated robot) or translational (linear) displacement. The links of the manipulator can be considered to form a kinematic chain. The terminus of the kinematic chain of the manipulator is called the end effecter and it is analogous to the human hand.

The following list specifies the functions of each axis.

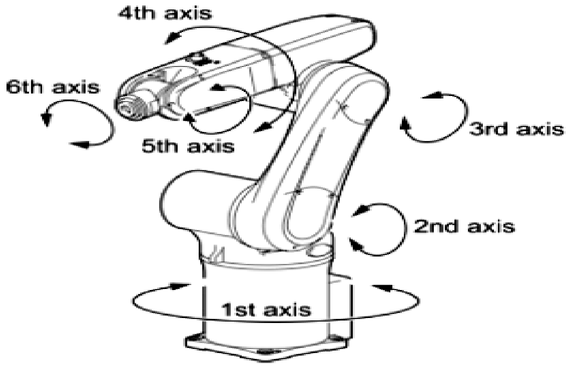


Fig1.Six axes of robotic arm

- Axis 1 – It is located at the base of a robot, and allows it to rotate from left to right.
- Axis 2 – It helps the lower arm of a robot to extend forward and backward.
- Axis 3 – It allows the upper arm of a robot to raise and lower.
- Axis 4 – This axis is known as wrist roll, and it rotates the upper arm of a robot in a circular movement.
- Axis 5 – It permits the wrist of the robot's arm to raise and lower.
- Axis 6 – It allows the wrist of the robot's arm to rotate freely in a circular motion.

II. LITERATURE SURVEY

We have done the literature survey of total fifteen research papers. From the various paper we have studied, basically the paper explained about the robotics,sensor , controller and the programming. The papers have discussed the use of robotic arm for automation in various applications such as NDT, extrusion die finishing, assembly of automobile etc. The force torque sensors were developed using strain gauges for space robot. Many of the robotic arm developed were for specific application and constrained working space.

Mineo et al.(2016) presented work undertaken for the development of robot manipulator based automated NDT system. This approach directly influenced the development of a MATLAB toolbox targeted to NDT automation, capable of complex path planning, obstacle avoidance, and external synchronization between robots and associated external NDT systems. A new software solution was presented that enables flexible trajectory planning to be accomplished for the inspection of complex curved surfaces often encountered in engineering production. The techniques and issues associated with conventional manual inspection techniques and automated systems for the inspection of large complex surfaces were reviewed. Obstacle avoidance and external synchronization between robots and associated external NDT systems. This paper highlights the advantages of this software over conventional off-line-programming approaches when applied to NDT measurements. An experimental validation of path trajectory generation on a large and curved composite aerofoilcomponent, is presented.

Wilbert et al.(2015) presented robot integrated finishing process and the essay focused on the automated finishing of a real extrusion die. The programming of the robot arm movement was done through CAM software. Integrated into the six-axis robot, a pneumatic compliant spindle was adopted in order to deburr and grind the large spectrum of freeform topographies.The first step of the investigation was to identify and quantify the process parameters influence to the surface quality that would be applied in the real extrusion die finishing. Based on an empiric parameters model, a real extrusion die was finally finished automatically, taking into account the established parameters for a projected surface quality. Further more, due to difficulties encountered during the trials, a sequential and simple evaluation of the robot accuracy in similar conditions of the experiment was conducted to identify and understand robot behaviour and quantify deviations.

Plooijet al.(2015) considered rest-to-rest motions of robotic arms that use only feed forward control. theyshown that it was possible to design feed forward controllers such that the final position of the motion is robust to uncertainty in the friction model. they studied a one DOF robotic arm in the horizontal plane, of which we show analytical, simulation and hardware results and we also show simulation results of a planar two DOF arm. Our friction model includes three types of friction: viscous, Coulomb and torque dependent friction. The results show that it was possible to eliminate the sensitivity of the final state to uncertainty in the three types of friction.

Sun et al.(2015) designed the six-axis force/torque sensor for space robot. The six-axis force/torque sensor equipped on the space robot could sense the three orthogonal forces and torques simultaneously, which will play an important role in the force control of space robot. Considering the dimension and compatibility, they designed a novel six-axis force/torque sensor based on strain gauges for the space robot. Different with the traditional Maltese cross beam, it is a novel structure with through-hole beam. Compared with the usually optimization method by trial and error, employing the response surface methodology (RSM) to acquire the optimum dimensional parameters is proposedin this paper.The experimental results show a good performance of nonlinearity, repeatability, stability, hysteresis, sensitivity, and accuracy.

Vongbunyong et al.(2015) implemented a principle of cognitive robotics to address the problem regarding uncertainties and variations in the automatic disassembly process. In this article, advanced behaviour control based on two cognitive abilities, namely learning and revision, are proposed. The knowledge related to the disassembly process of a particular model of product is learned by the cognitive robotic agent (CRA) and will be implemented when the same model has been seen again. This knowledge is able to be used as a disassembly sequence plan (DSP) and disassembly process plan (DPP). The agent autonomously learns by reasoning throughout the process.As a result, the performance of the process regarding time and level of autonomy are improved. The validation was done on various models of a case-study product, Liquid Crystal Display (LCD) screen.

Zhao et al.(2014) studied generation of trajectories of both end-effector and joints for human-like reaching and grasping motions is studied. In reaching movement, the human-like end-effector trajectory was obtained based on the minimum jerk model. A total potential energy criterion was constructed to resolve the kinematic redundancy of human arm in the target position. Gradient Projection Method (GPM) was adopted to trace the human-like end-effector trajectory while minimizing the total potential energy to generate the human-like joint trajectory. The criteria and algorithm are verified by simulations and experiments.

Tsarouchi et al.(2014) investigated into the use of a dual arm robot system for performing manual assembly operations. The investigation was based on a case study, originating from the final assembly area of an automotive assembly plant. The motivation as well as the benefits derived from the employment of a dual arm robot is discussed. The station layout, tooling design and robot programming were elaborated. The use of a dual arm robot enabled the performance of operations that were carried out by humans, while the comparison of using single arm robots offered a number of advantages, which were discussed in the paper. The assembly of a vehicle dashboard was used as the use case coming from the automotive industry.

Bernal et al.(2014) studied that brain–machine interfaces can greatly improve the performance of prosthetics.

Utilizing biomimetic neuronal modeling in brain machine interfaces (BMI) offers the possibility of providing naturalistic motorcontrol algorithms for control of a robotic limb. This will allow finer control of a robot, while also giving us new tools to better understand the brain’s use of electrical signals. However, the biomimetic approach presented challenges in integrating technologies across multiple hardware and software platforms, so that the different components can communicate in real-time. they presented the first steps in an ongoing effort to integrate a biomimetic spiking neuronal model of motor learning with a robotic arm. This work paves the way towards a full closed-loop biomimetic brain-effector system that can be incorporated in a neural decoder for prosthetic control, to be used as a platform for developing biomimetic learning algorithms for controlling real-time devices.

Manzoor et al.(2014) presented an autonomous robotic framework for academic, vocational and training purpose. The platform is centred on a 6 Degree Of Freedom (DOF) serial robotic arm. The kinematic and dynamic models of the robot have been derived to facilitate controller design. An on-board camera to scan the arm workspace permits autonomous applications development. The sensory system consists of position feedback from each joint of the robot and a force sensor mounted at the arm gripper. Advanced users can tailor the platform by exploiting the open-source custom-developed hardware and software architectures.The proposed platform finds its potential to teach technical courses (like Robotics, Control, Electronics, Image-processing and Computer vision) and to implement and validate advanced algorithms for object manipulation and grasping, trajectory generation, path planning, etc. It can also be employed in an industrial environment to test various strategies prior to their execution on actual manipulators.

Keating et al,(2013) proposed a novel approach for robotic fabrication and manufacturing entitle Compound Fabrication, supporting multifunctional and multi-material processes. This approach combined the major manufacturing technologies including additive, formative and subtractive fabrication, as well as their parallel integration. A 6-axis robotic arm, repurposed as an integrated 3D printing, milling and sculpting platform, enables shifting between fabrication modes and across scales using different end effectors. Promoting an integrated approach to robotic fabrication, novel combination processes were demonstrated including 3D printing and milling fabrication composites. In addition, novel robotic fabrication processes were developed and evaluated, such as multi-axis plastic 3D printing, direct recycling 3D printing, and embedded printing. The benefits and limitations of the Compound Fabrication approach and its experimental platform were reviewed and discussed. Finally, contemplation regarding the future of multi-functional robotic fabrication was offered, in the context of the experiments reviewed and demonstrated in this paper.

Basile et al.(2012) proposed a task-oriented motion planning approach for general cooperative multi-robot systems. In order to derive a meaningful task formulation, a taxonomy of cooperative multi-arm systems of industrial interest was devised. Then, a workpiece-oriented general formulation for cooperative tasks was proposed, where the user was asked to specify the motion of the system only at the workpiece level, while the motion of the single arms in the system is computed via kinematic transformations between the relevant coordinate frames. Based on this task formulation, an instructions set was derived to extend classical programming languages for industrial robots to general multi-robot systems. In order to test the approach, a software environment has been built, composed of an interpreter of the language and the motion planning software.

Zhou et al.(2012) proposed a drive train optimization method for design of light-weight robots. Optimal selections of motors and gearboxes from a limited catalog of commercially available components were done simultaneously for all joints of a robotic arm. Characteristics of the motor and gearbox, including gear ratio, gear inertia, motor inertia, and gear efficiency were considered in the drive train modelling. A co-simulation method was developed for dynamic simulation of the arm. A design example was included to demonstrate the proposed design optimization method.

Sharma et al.(2011) designed and demonstrated a dexterous anthropomorphic mobile robotic arm with nine degrees of freedom using readily available low-cost components to perform different object picking tasks for immobile patients in developing nations. The robotic arm consists of a shoulder, elbow, wrist and five-finger gripper. It can perform different gripping actions, such as lateral, spherical, cylindrical and tip-holding gripping actions using a five-finger gripper; each finger had three movable links. The actuator used for the robotic arm was a high torque dc motor coupled with a gear assembly for torque amplification, and the five-finger gripper consists of five cables placed like tendons in the human arm. The arm can be programmed or controlled manually to perform a variety of object-picking tasks. A prototype of the robotic arm was constructed, and test results on a variety of object-picking tasks were presented.

Rustemli et al.(2010) presented the control of two axis robot arm. The system was consisted of two step motors, robot arm, computer and PIC16F84A. One of them controls the robot arm via parallel port of the computer. The other one controls end element on the arm by PIC16F84A. PIC16F84A drives the motor by the designed circuit drive. Although the control of the step motor was very easy, they work choppily. Therefore, it was necessary to reduce the ripples occurred at the speed and torque of the step motor. In this study, proportional–integral–derivative (PID) controller was used to reduce the ripples. The obtained results show the proposed method was very successful.

The research work done for designing and manufacturing of robotic arm was for specific applications only such as NDT, extrusion die finishing, assembly and disassembly of automobiles. The programming was done using the softwares as Matlab, CAD which requires the drawing of the object for programming. If the application is changed then whole robotic system must have to be reprogrammed which is time consuming and costly. The research done was basically on three and four axis robotic arm which constrains the motion of the arm to move in the working envelope. The payload for the pick and place application is limited upto 2 kg which is undesirable in many applications. Hence we have designed the universal robotic arm which can perform multiple applications upto 10 kg pay load and 1 m^3 volume.

III. PROBLEM STATEMENT

In today industries, most of the factories run by the automated robots in order to deal with their production activities in the automation field which uses the robotic arm for welding, material handling, assembly, spray painting and drilling.

Although there are many robotic products available in market, none of them is cheaper in terms of price. The industry has to perform the different operations, for which the different robotic arm is to be designed and fabricated. This process is very costlier and also time consuming. The existing robotic arms are designed based on the specific application and operation. They cannot be reprogrammed for any other application or operation. Also the most of the robotic arm are too bulky.

Hence we are designing and manufacturing the six axis universal robotic arm which can perform the different operations with greater flexibility and automation. The wrist of the robotic arm is changeable for performing the different application within the working envelope.

IV.METHODOLOGY

The methodology of the project mainly consist of following two stages-

i. First stage-To design a six axis robotic arm which can be controlled by the PLC program as per required process. Selection of different parameters and components.

This stage includes

a) Study of the robotic arm and automation thoroughly.
b) Study different research papers related to the project and do literature survey.
c) Design of the robotic arm and selection of the different components and parameters
d) Validate the design and selection of component analytically and using analysis software

ii. Second step-objective- To manufacture and assemble robotic arm and implement it in maximum applications possible.

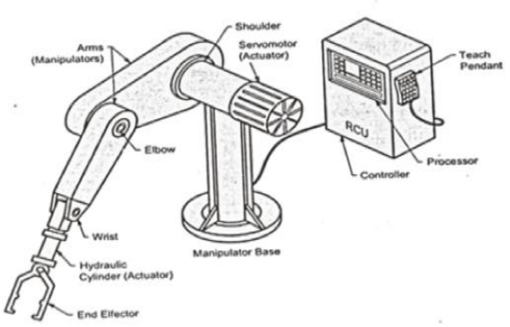
This stage includes

a) Manufacturing and assembly of the robotic arm and different components
b) Manufacturing the end effectors for respective applications.
c) Synchronizing the robotic arm with the control system.

V. SPECIFICATION OF ROBOTIC ARM

The design of robotic arm is to be done with following specifications.

Sr. No.	Specification	Requirement
1.	Payload	10 Kg
2.	Working Envolope	1 m^3
3.	Configuration.	Spherical
4.	DOF	6
5.	Accuracy	+_ 0.5 mm
6.	Resolution	+_ 0.5 mm
7.	Repeatability	0.01 mm
8.	Actuator	Electric or Pneumatic
9.	End Effector	Mechanical Gripper, spray and riveting gun
10.	Controller	Electronic Sequence
11.	Sensor	Force Sensor, pressure sensor
12.	Programming	Lead through or textual programming
13.	Application	Pick And Place, spray painting, riveting



VI. DESIGN OF ROBOTIC ARM

To proceed in the direction of design aspects, first mechanical structure has to be designed. Depending on the design requirements electronic parts are configured with that of mechanical design.

Mechanical design involves the selection of suitable motor for our application, deciding on the material to be used for the construction of the arm, i.e the shaft material and deciding on the location where the motor has to be placed.

SELECTION OF MOTOR

The main criteria to be considered while selection of motor is Torque and the speed of the motor, many different motors are available in the market like servomotors, stepper motor, dc motors with and without gears. These different motors are used according to their applications and requirements. for e.g. If we want high torque and precise speed we need to use servo motors, if we want to only position and if high torques not required then stepper motors are used. The motor can be selected once we know the torque and speed required for our application.

TORQUE AND SPEED CALCULATION

The main criteria to be considered for the selection of motor are torque and speed.

Torque calculation

Torque is the tendency of force to rotate an object about an axis. Mathematically, torque is defined as the cross product of the lever-arm distance and force, which tends to produce rotation. i.e.

$T= F * L$ Nm

Where, F= force acting on the motor
L= length of the shaft

Force, F is given by,
$F= m * g$ N
Where, m=mass to be lifted by the motor
g= gravitational constant = 9.8 m/s

Calculation of the torque starts from the gripper and moves downward till the base joint of the arm. Hence base Joint carries the maximum payload i.e it should carry the weight of the upper 2 motors also. The robotic arm is of three joints. One motor each at the 3 joints. The torque and speed calculation differs at each joint depending on the payload.

By trajectory planning method,
L_1= 0.3 m, L_2= 0.66 m, L_3= 0.22 m
Weight to be lifted= 10 kg
Weight of the gripper=0.2 kg

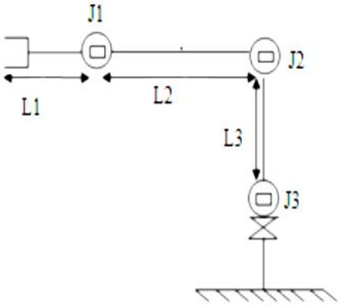


Fig3. Links of robotic arm

I) For joint 1,
Total weight on motor 1=10+0.2= 10.2 kg
Force acting on motor 1,

F_1= 10.2*9.81= 100 N

Torque on motor 1= 100*0.3= 30 Nm

T_1=30 Nm

II) For joint 2,
Weight of motor 1= 0.1 kg
Weight of link 2=0.15 kg
Total weight on motor 2=10.2+0.1+0.15= 10.45 kg
Force acting on motor 2,

F_2= 10.45*9.81= 102.51 N

Torque on motor 1= 102.51*(0.3+0.66)= 98.41 Nm

T_2=98.41 Nm

III) For joint 3,
Weight of motor 2= 0.2 kg
Weight of the 3=0.15 kg
Total weight on motor3=10.45+0.2+0.15= 10.8 kg
Force acting on motor 3,

F_3= 10.8*9.81= 105.94 N

Torque on motor 3,
T_3= 102.51*(0.3+0.66+0.22)= 125 Nm

T_3=125 Nm

Design of gripper:

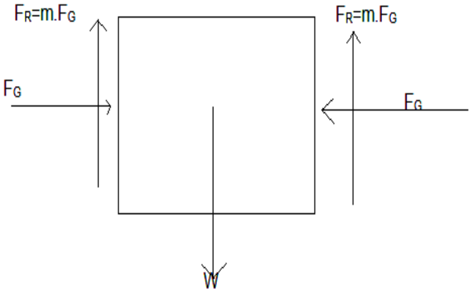


Fig4. Gripper force diagram

Considering the vertical equilibrium condition,

$$2u*F_g = mg$$
$$2*0.25*F_g= 10*9.81$$
$$F_g= 196.2 \text{ N}$$

Torque on gear,

$$T=f_{g\,*}L=196.2*0.2$$
$$T=39.24 \text{ Nm}$$

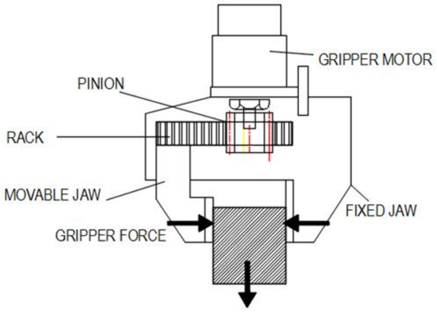


Fig5. Rack and pinion mechanism for gripper

VII.CONCLUSION

This project finds the many applications in various fields to perform multiple applications such as pick and place, drilling, spray painting, riveting, welding etc. The replaceable end effector of the robotic arm reduces cost and time of manufacturing the whole robotic arm and helps industry to perform different operations with same arm.

ACKNOWLEDGMENT

With great pleasure we express our deep sense of gratitude to our project guide Prof.N.V.Lakal for his valuable guidance, discussion and constant encouragement for successful completion of this project work. They gave us suggestion and constructive criticisms from time to time in friendly manner, which is perhaps a unique characteristic nature of their mind.

We would like to thank them very much for their unwavering support and understanding, as well as his insights on the subject. The completion of this project required more than just academic support so we are thankful to everyone who helped us directly or indirectly for the completion of the project.

We are highly obliged to our respected HOD Dr. V.V.Shinde and the entire Mechanical Department staff for fostering a creative and educational environment for us. Also, no acknowledgement is complete without thanking our Principal, Dr. M. S. Gaikwad, for allowing us to pursue our project and our degree from this fine institution of higher education.

REFERENCES

[1] MineoC.,Pierce S. G., Nicholson P.L., Cooper I., “Roboticpath planning for non- destructive testing–A custom matlab toolbox approach”, Robotics and Computer-Integrated Manufacturing 37, (2016) pp.1–12.

[2] Wilbert A.D., Behrens B., Zymla C., Dambon O., Klocke F., "Robotic finishing process – An extrusion die case study", CIRP Journal of Manufacturing Science and Technology , (2015) pp. 1-8.

[3] Plooij M., Wolfslag W., Wisse M., "Robust feed forward control of robotic arms with friction model uncertainty", Robotics and Autonomous Systems 70, (2015) pp.83–91.

[4] Sun Y., Liu Y., Zou T., Jin M., Liu H., "Design and optimization of a novel six-axis force/torque sensor for space robot", Measurement 65, (2015) pp.135–148.

[5] Vongbunyong S., Kara S., Pagnucco M., "Learning and revision in cognitive robotics disassembly automation", Robotics and Computer-Integrated Manufacturing 34, (2015) pp.79–94.

[6] Zhao J., Xie B., Song C., "Generating human-like movements for robotic arms", Mechanism and Machine Theory 81, (2014) pp.107–128.

[7] Tsarouchi P., Makris S., Michalos G., Stefos M., Fourtakas K., Kaltsoukalas K., Kontrovrakis D., Chryssolouris G., "Robotized assembly process using Dual arm robot", CIRP 23, (2014) pp.47 – 52.

[8] Bernal S. D., Chadderdon G. L., Neymotin S. A., Francis J. T., Lytton W. W., "Towards a real-time interface between a biomimetic model of sensorimotor cortex and a robotic arm", Pattern Recognition Letter 36, (2014) pp.204–212.

[9] Manzoor S., Islam R. U., Khalid A., Samad A., Iqbal J., "An open-source multi-DOF articulated robotic educational platform for autonomous object manipulation", Robotics and Computer-Integrated Manufacturing 30, (2014) pp.351–362.

[10] Keating S.,Oxman N., "Compound fabrication: A multi-functional robotic platform for digital design and fabrication", Robotics and Computer-Integrated Manufacturing 29, (2013) pp.439–448.

[11] Basile F., Caccavale F., Chiacchio P., Coppola J., Curatella C., "Task-oriented motion planning for multi-arm robotic systems", Robotics and Computer-Integrated Manufacturing 28, (2012) pp.569–582.

[12] Zhou L., Bai S., Hansen M. R., "Design optimization on the drive train of a light-weight robotic arm", Mechatronics 21, (2012) pp.560–569.

[13] Sharma A., Noel M. M., "Design of a low-cost five-finger anthropomorphic robotic arm with nine degrees of freedom", Robotics and Computer-Integrated Manufacturing 28, (2011) pp.551–558.

[14] Rustemli S, Yilmaz M, Demirtas M., "Ripple reduction at speed and torque of step motors used on a two-axis robot arm", Robotics and Computer-Integrated Manufacturing 26, (2010) pp.759–767.