Workspace Analysis of Various Robots for Wall Painting Application

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Abstract - Despite the advances in robotics and its wide spreading applications, wall painting has shared little in research activities. The paint which is used for wall painting application contains hazardous chemical in it, which causes eye and respiratory system problems to the human painters. Also the wall painting procedure requires repeated work which makes the process time and effort consuming. These problems motivates for the development of an automated robot for wall painting application. In this paper, different types of robots structures and their respective workspace analysis are studied for wall painting application. The detailed study of Cartesian Robot is also studied, and concluded that whether the Cartesian Robot is suitable for wall painting application or not. The most important requirements to take into account were those regarding: Degrees of freedom, ease of programming, work accuracy, dimensions, workspace, work volume, work envelope, arm configuration and structure.

Keywords — Robotics, workspace, work volume, work envelope, Cartesian Robot.

I. INTRODUCTION

The word robot originated from Czech word "*robota"* meaning of *robota* is work. Webster's dictionary defines robot as "an automatic device that performs functions ordinarily ascribed to human beings." A definition used by Robot Institute of America gives a more precise description of industrial robot: "A robot is reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices, through variable programmed motion for the performance of a variety of task." In short, a robot is reprogrammable general purpose manipulator with external sensor that can perform various assembly tasks. With this definition, a robot must possess intelligence, which is normally due to computer algorithms associated with its control and sensing system [1]. Despite the advances in robotics and its wide spreading applications, wall painting has shared little in research activities. The robot is an automatically controlled, reprogrammable, multipurpose mechanical system with several degrees of freedom, which may be either fixed in place or mobile. It has been widely used in various automation applications. Since the last decade, other areas of application have emerged such as medical, transport, underwater, entertainment, painting, military, material handling, space, welding, assembly etc. The basic robotic system broadly defines the mechanics, control, and sensor design of Robots. Mechanics includes the design and structure of manipulators, arms, end effectors, actuators, and energy storage. It also consists of the kinematics, dynamics of Robots, and simulation of Robot Systems. Control includes both theory and implementation (hardware and software) while Sensors include design of sensor systems and algorithms for sensory data acquisition and analysis.

Stiffness modeling, analysis, synthesis and control in robotic machining have attracted the attention of many researchers. To have analysis of Cartesian robot for wall painting application is just because of there are many advantages are there of Cartesian robot over the other robot. The Cartesian robot have simplest configuration, the link of the manipulator are constrained to move in a linear manner. In addition, they have good repeatability and accuracy (even better than the SCARA types) and are easier to program because of the natural coordinate system. Three Degree of Freedom (DOF) is primary requirement for wall painting application and this requirement can be fulfill by the Cartesian robot. Also the robot manipulators are highly required in many kinds of industrial tasks not only electrically driven robots but also hydraulically driven robots such as spray painting, arc welding, excavator and surgery for human [2]. Among several tasks to be automated, one may regard straight-line motion as one of the most fundamental and essential task. In order to automate straight-line motion, Cartesian-space control must be used. In other words, the end-effector of the manipulator needs to be controlled to track a linear path on the task space.

II. TYPES OF ROBOTS

There are two types of robots in usual. One is electrically driven robots and the other is hydraulically driven robot. Both of them have characteristics. Model-based control algorithms have been studied in electrically driven robots to improve position and tracking performance compared to classical approaches. There are some advantages in hydraulic driven robots those are the high power-to-weight ratio, the stiffness and the short response time. In particular, the hydraulically driven manipulators, being massively coupled and complexly connected and having at the same time various nonlinear components; contain numerous forms of severe nonlinearities that are hardly observed in electrically driven robots [3]. As a result, the end-effector control in task space of a hydraulically driven manipulator becomes significantly more difficult than the Cartesian-space control of a typical robot driven by electric motors.

An industrial robot is a general purpose, computer controlled manipulator consisting of several rigid links connected in series by prismatic or revolute joints. The motion of joints results in relative motion of the links. Many commercially available industrial robots are widely used in manufacturing and assembly task, such as spot welding, arc welding, material handling, paint spraying, loading and unloading numerically controlled machines, and for handling hazardous materials. These robots fall in to one of the four basic motion defining categories [1].

1. Cartesian coordinates (three linear axes) (e.g., IBM’s RS-1 robot and the Sigma robot from Olivetti)
2. Cylindrical coordinates (two linear and one rotary axes) (e.g., Versatran 600 robot from Perb)
3. Spherical coordinates (one linear and two rotary axes) (e.g., Unimate 2000B from Unimation Inc.)
4. Revolute or articulated coordinates (three rotary axes) (T^3 from Cincinnati Milacron and PUMA from Unimation Inc.)

III. ROBOT ANATOMY

The manipulator or robotic arm has many similarities as that of human body. The mechanical structure of a robot is like the skeleton in the human body. The robot anatomy is therefore the study of skeleton of robot that is the physical construction of the manipulator structure. The structure of a manipulator that consist of rigid bodies (links) connected by means of articulations (joints), is segmented into an arm that ensures mobility and reachability, a wrist that confers orientation, and an end effecter that performs the required task [4]. Most manipulators are mounted on a base fastened to the floor or on the mobile platform of an automated guided vehicle (AGV).

Robot types	**Axis 1**	**Axis 2**	**Axis 3**
Cartesian	P	P	P
Cylindrical	R	P	P
Spherical	R	R	P
Revolute	R	R	R

Table 1. Types of Robots and its Joints configurations.

IV. DEGEES OF FREEDOM

The number of independent movements that an object can perform in a 3D space is called number of degrees of freedom (DOF). Many types of joints can be made between two links. However only two basic types that are commonly used in the industrial robots are,

- Revolute (R)
- Prismatic (P)

According to joint movements and arrangements of links, four well distinguished basic structural configurations are possible for the arm. These are characterized by the distribution of three arm joints among prismatic and rotary joints, and are named according to the coordinate system employed or the shape of the space they sweep. The four basic configurations are:

(1) Cartesian (rectangular) configuration – all three Prismatic joints
(2) Cylindrical configuration – one Revolute and two Prismatic joints.
(3) Polar (spherical) configuration – two revolute and one Prismatic joint.
(4) Articulated (revolute or jointed arm) configuration – All three revolute joints.

Depends on different number of links, joints, prismatic and revolute joints the degrees of freedom of that particular robot is going to change. Different robots are having different joints some of them are listed as given below in the table.

The relative motions in between the two joining links are either rotary or linear depending on the type of joint. In revolute joint the two links are joined by a pin about the axis of which the links can rotates with respect to each other. While in the prismatic joint the two links are so jointed that this can slide linearly with respect to each other. As the different robot have different structure, different angular and linear movements, different joints and different degrees of freedoms.

V. ARM CONFIGURATION AND WORK SPACE ANALYSIS

The mechanism of the arm with 3 – DOF depends on the type of three joints employed and there arrangement. The purpose of the arm is to position the wrist in the 3-D space and the arm has following characteristic requirements.

- Links are long enough to provide for maximum reach in the space.
- The design is mechanically robust because of the arm has to bear not only the load of work piece but also has to carry the wrist and the end effector.

Work space of the robot is based on the length of links, types of joints and relative motion between the link and joint. Each of the work space analysis is discussed briefly.

1. Cartesian (rectangular) configuration

This is the simplest configuration with all three prismatic joints as shown in figure. It is constructed by three perpendicular slides, giving only linear motions along the three principal axes. There is an upper and lower limit for movement of each link. The endpoint of the arm is capable of operating in cuboidal space, called workspace. The workspace represents the portion of space around the base of manipulator that can be assessed by the arm end point. The shape and size of the workspace depends on the arm configuration, structure, degrees of freedom, size of links, and design of joints. The physical space that can be swept by a manipulator may be more or less than the arm endpoint workspace. The volume of the space swept is called work volume the surface of the workspace describes the work envelop.

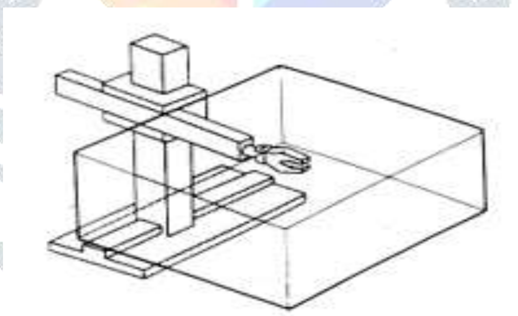

Fig. 1. A 3-DOF Cartesian arm configuration and its workspace [4].

The workspace of Cartesian configuration is cuboidal and is shown in Fig. 1. Two types of constructions are possible for Cartesian arm: a Cantilever Cartesian and a gantry or box Cartesian. The latter one has the appearance of a gantry type. Despite the fact that Cartesian arm gives high precision and easy to program, it is not preferred for many applications due to limited manipulability. Gantry configuration is used when heavy load must be precisely moved. The Cartesian configuration gives large work volume.

2. Cylindrical configuration

The cylindrical configuration as shown in Fig. 2 uses two perpendicular prismatic joints, and one revolute joint. The difference from the Cartesian one is that one of the prismatic joint is replaced with revolute joint. One typical construction is with the first joint as a revolute. The rotary joint may either have the column rotating or a block revolving around a stationary vertical cylindrical column. The vertical column carries a slide that can be moved up or down along the column. The horizontal link is attached to the slide such that it can move linearly, in or out, with respect to column. This result in a RPP configuration. The arm end point is, thus, capable of sweeping a cylindrical space. To be precise, the workspace is a hollow cylinder as shown in Fig. 2. Usually a full 360o rotation of the vertical column is not permitted due to mechanical restrictions imposed by actuators and transmission elements.

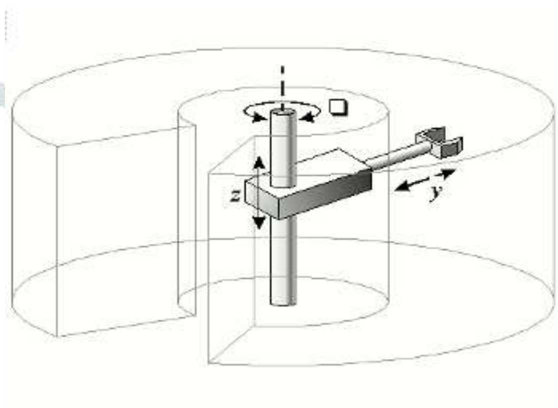

Fig. 2. A 3-DOF cylindrical arm configuration and its workspace [4].

Many other joint arrangements with two prismatic and one rotary joint are possible for cylindrical configuration, for example, a PRP configuration. All combination of 1R and 2P are not useful configurations as the may not give suitable workspace and some may only sweep a plane. Such a configurations are called nonrobotic configurations. The cylindrical configuration offers good mechanical stiffness and the wrist positioning accuracy decreases as the horizontal stroke increases. It is suitable to access narrow horizontal cavities and, hence, is useful for machine loading operations.

3. Polar (Spherical) configuration

The polar configuration illustrated in Fig. 3. It consists of a telescopic link (prismatic joint) that can be raised or lowered about a horizontal revolute joint. These two links are mounted on a rotating base. This arrangement of joints, known as RRP configuration, gives the capability of moving the arm end point within a partial spherical shell space as work volume.

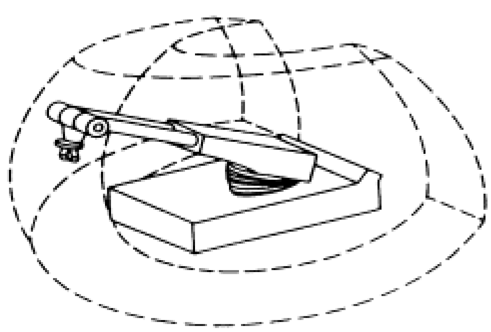

Fig. 3. A 3-DOF polar arm configuration and its workspace [4].

This configuration allows manipulation of objects on the floor because its shoulder joint allow its end effector to go below the base. Its mechanical stiffness is lower than Cartesian and cylindrical configurations and the wrist positioning accuracy decreases with the increasing radial stroke. The construction is more complex. Polar arms are mainly employed for industrial application such as machining, spray painting and so on. Alternate polar configuration can be obtained with other joint arrangement such as RPR, but PRR will not give a spherical work volume.

4. Articulated (Revolute or Jointed-arm) configuration

The articulated arm is a type that best simulates a human arm and manipulator with this type of an arm is often referred as an anthropomorphic manipulator. It consist of two straight links, corresponding to the human "forearm" and "upper arm" with two rotary joints corresponding to the "elbow" and "shoulder" joints. This two links are mounted on a vertical rotary table corresponding to the human waist joint. Fig. 4. illustrates the joint link arrangement for articulated arm.

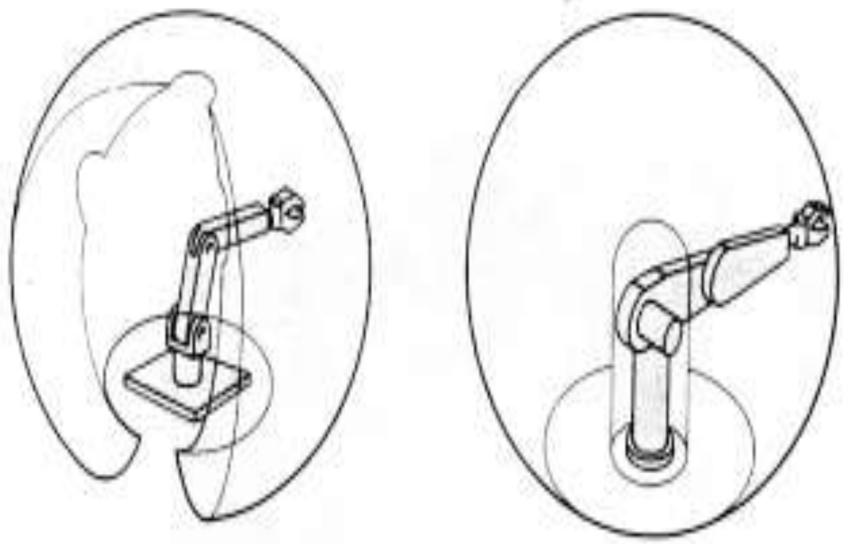

Fig. 4. A 3-DOF articulated arm configuration and its workspace [4].

This configuration RRR is also called revolute because three revolute joints are employed. The work volume of this configuration is spherical shaped, and with proper sizing of links and design of joints, the arm endpoint can sweep a full spherical space. The arm endpoint can reach the base point and below the base, as shown in Fig. 4. This anthropomorphic structure is the most dexterous one, because all the joints are revolute, and the positioning accuracy varies with arm endpoint location in the workspace. The range of industrial applications of this arm is wide.

VI. CONCLUSION

This paper has described the workspace analysis of various robots. The importance of critical zone is studied and its requirements are specified. The analysis shows that the Cartesian robot is fulfilling most of the requirements of wall painting application such as its simplest configuration with all three prismatic joints, it is constructed by three perpendicular slides, it gives only linear motions along the three principal axes, The endpoint of the arm is capable of operating in cuboidal space, they have good repeatability and accuracy and are easier to program because of the natural coordinate system. However, this approach still has challenges that the large gap exists between the conventional (Manual) and automated (Robotic) wall painting application. It is nearby expected to achieve Cartesian robot for the wall painting application.

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