Synthesis of a Manipulator of the New UWA Robot

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Abstract

This contribution presents the workspace analysis process leading to the development of the concept of a New University of Western Australia Robot - NUWAR. NUWAR is a variation of the well-known Delta parallel robot. It is of particular interest to determine, for given dimensions of a manipulator, how the size and shape of the robot workspace vary with values of two angles defining the orientation of motor axes. Finding the optimal values of these angels, from the point of view of the workspace volume, has been an objective of this study. Computer simulations indicated that the configuration described by motor axis inclination to the horizontal plane α=35.26 degrees and the angle between the motor axis and the sides of the base triangle β=60 degrees — known as the New University of Western Australia Robot - NUWAR — is advantageous over Delta configuration in terms of workspace volume and shape.

1 Introduction

Manipulators of parallel robots have the end effector moved around the workspace by a number of serial kinematic chains in parallel. This is a distinguishing feature of parallel robots when compared to the traditional, serial ones. The first written account of the parallel robot was provided by Pollard [Pollard, 1938] in his car painting mechanism patent application. In 1947 Mc Cough proposed a six-degree-of-freedomplatform, which was later used by Stewart in his flight simulator [Stewart, 1966].

Parallel manipulators possess a number of advantages when compared to traditional serial arms. They offer generally much higher rigidity and smaller mobile mass than their serial counterparts. These features allow much faster and more precise manipulations. Common to parallel mechanisms is their relatively reduced working volumes, which though smaller in comparison with serial arms of a similar size, are however usually more uniform and homogeneous, possessing no dead zones (unreachable regions). A catalogue describing a large variety of parallel configurations can be found in the book by Merlet [Merlet, 1990].

Because of their high rigidity and speed of manipulation parallel robots are particularly suited to a number of typical industrial applications and have presented a lot of interest to various researchers over the years. In recent years several new structures and mechanisms have been proposed, developed for a variety of both established and novel applications, such as packaging, assembly, haptic interfaces, etc. [Arai and Tanikawa, 1996; Badano et al., 1993; Clavel, 1988; Pierrot et al., 1991; Tsumaki et al., 1998].

This work was motivated by a need for a robot, which retaining qualities of Delta robot - currently one of the fastest robots in the world - would have improved workspace. We consider the feasibility of other configurations for three degree of freedom parallel robots, and discuss the potential advantages of a particular arrangement. Like the Delta, the robot considered in this paper consists of three kinematic chains in parallel, which connect the base to the end effector. It is of particular interest to determine, for given dimensions of a manipulator, how the size and shape of the robot workspace varies with values of two angles defining the orientation of motor axes. An objective of this study was investigating, whether the kinematic configuration with motor axes perpendicular to one another is advantageous over the Delta configuration.

2 DELTA Robot description

The DELTA robot (Fig 1) is an original design that arose from the need detected in the production and manufacturing sectors for manipulators better suited to the fast execution of light-duty tasks. As seen from the figure the three closed kinematic chains are identical and are actuated by three revolute electric motors (4 in Fig. 1) rigidly mounted to the top (robot base, 5 in Fig. 1), and closed below at the common tool-base (also known as the *travelling plate* or *nacelle,* 3 in Fig. 1). The combination of the constrained motion of these three

chains ensues in a resulting three translatory degrees of freedom for the robot tool-base. Each chain consists of an arm (1 in Fig. 1) whose length represents a transmission factor amplification through the parallel rods (parallelogram, 4 in Fig. 1) at the elbow. These rods transmit and convert the revolute actuator motion into the linear displacements of the tool-base. The three degrees of freedom obtained are the x, y, z displacements of the tool-base within the robot's working volume; and its relative orientation is maintained fixed in an entirely passive manner.

The configuration currently under study is a symmetrical one and consists of the three chains between the robot base and the travelling plate, which are identical and arranged at 120 degrees to one another; the axes of the actuators of each arm are co-planar and tangential to the same circle. The arms describe planar circles. The articulations (6 in Fig. 1) that join the three pairs of parallel rods to the travelling plate are situated on the three sides of an equilateral triangle. Other configurations are possible but will not be touched upon here. From this point on, for simplicity's sake, the Π plane (Fig. 1) will be considered horizontal and the planes in which the arms move to be vertical. The Tool Centre Point (TCP) is given by the intersection of three spheres whose origins are to be found at the arm's elbows.

3 Workspace Analysis of Delta–Type Robots

The starting point of the analysis presented in this study was the Delta Robot, Figure 1. The modifications to the Delta Robot, leading to the increase in workspace volume were considered. In order to quickly analyse different configurations, mathematical modelling and computer simulation approach was employed. In all mathematical models the Z axis is perpendicular to the base plane and points vertically up. The X and Y axes are located in the baseplane, with the X axis pointing towards motor #1. The origin is located at the point equidistant to the three motors.

The computer models of the robots were written parametrically so that different configurations can easily be analysed. Mechanical simulation package ADAMS [ADAMS, 1993] and AutoCad/AutoLisp [AutoCad, 1997] were used. The objective was to increase the workspace volume without changing the dimensions of the robot. Therefore, in addition to the dimensions of each component, two design variables - the angles α and β - have been introduced, see Figure 2. These two angles determine the orientation of each motor axis (ie. the controlled revolute joint axes which connect the arms to the base). As the arm is always perpendicular to its motor axis, the angles α and β control the orientation of the three arm/forearm assemblies. Varying α and β angles leaves the locations of the three motors unchanged.

All dimensions have been chosen as in DELTA-740 [Guglielmetti, 1994]:

- length of the arm from joint to joint - 0.26m
- length of the forearm from joint to joint - 0.48m
- radial distance of each motor from the centreline - 0.194m
- displacement in radial direction of the midpoint of each pair of spherical joints on the travelling plate - 0.03m
- spacing of the forearms - 0.05m
- angular limit of lateral rotation of the universal joints which join the arms to the forearms - 60 degrees

The design variables used in the models are α - the inclination of each motor to the horizontal, a positive

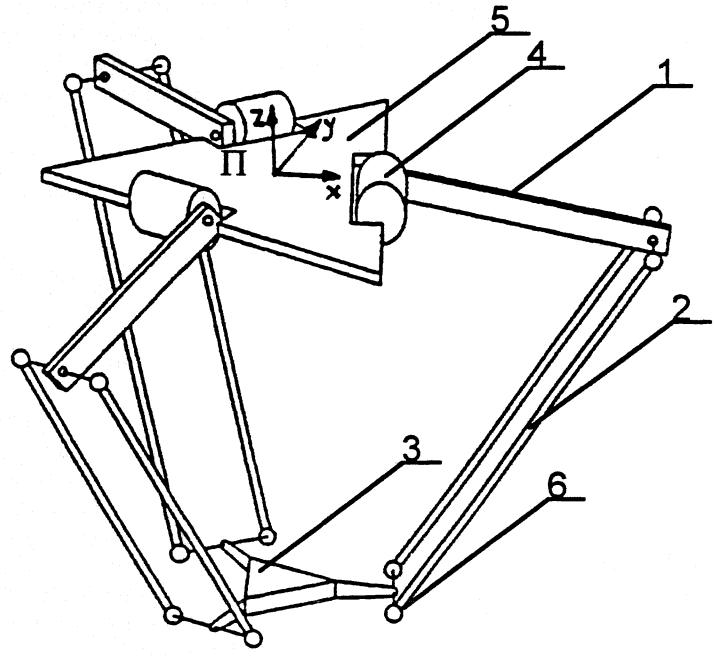

Figure 1. General lay-out of the DELTA robot.

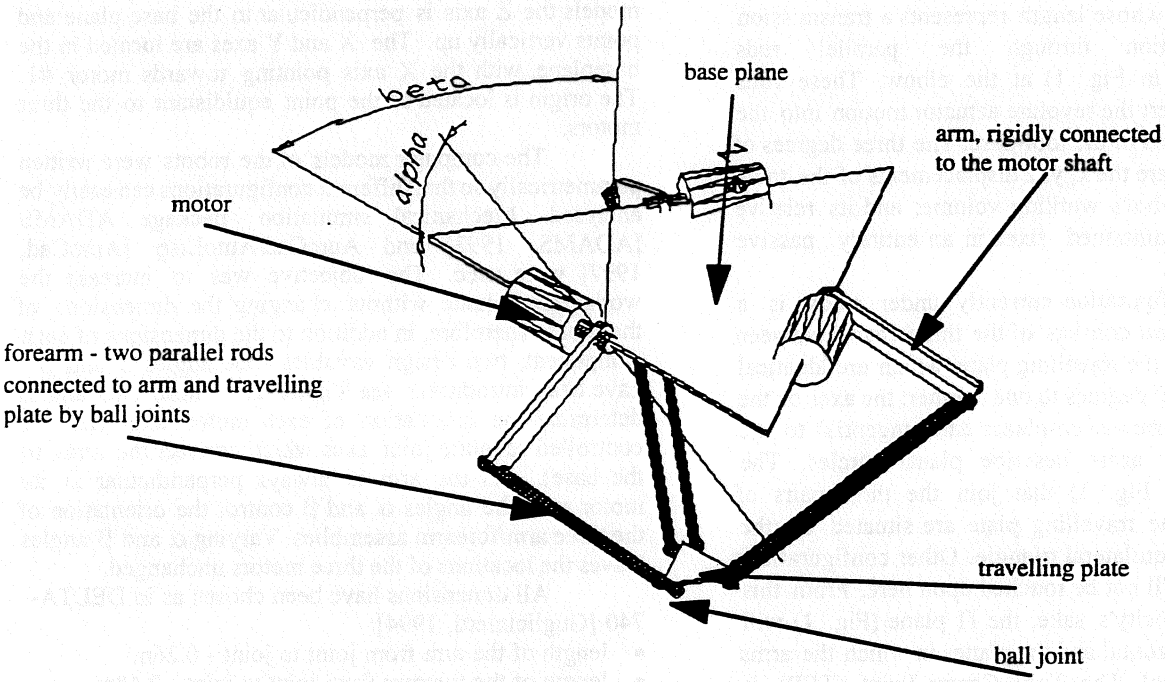

Figure 2. Design variables α and β.

value rotates the motor in a clockwise direction when viewed from the outside (for Delta robot α = 0 degrees), and β - rotation of each motor with respect to the vertical (Z) axis (for Delta robot β =0 degrees).

By considering each arm individually, the volume that can be reached by each arm can be determined. The volume that can be reached by a single arm assembly is a torus centred on the base revolute joint, with the major radius being the length of the arm and the tube radius being the length of the forearm. The angular limit of the universal joints must also be accounted for (by intersecting the torus with a box), as must the central void in the torus that occurs when the forearm is longer than the arm. This volume represents the space that can be reached by the end of the forearm. In order to represent the volume that can be reached by the centre of the travelling plate, the displacement of the centre of the travelling plate from the spherical joint midpoint must be taken into account. As the orientation of the travelling plate is constant, each volume is simply displaced by this offset. The intersection of all three volumes is then the workspace that can be reached by the centre of the travelling plate.

The robot's workspace was derived using AutoCAD. A generalised program was written using AutoLISP in terms of the design variables mentioned above. Additionally a parametric model of the robots was constructed using ADAMS. The ADAMS models contain eleven rigid parts. These are: ground (ie. the base of the robot), three arms, six forearms, and the travelling plate. ADAMS constraints were used to define the relationship between various parts so that the model is not overconstrained and it does not possess additional "internal" degrees of freedom. The constraints used are: revolute joints (1 DOF, to define the relationship between the base and each arm), universal joints (2 DOF, to represent the relationship between each forearm and its parent arm), and spherical joints (3 DOF rotation, to define the relationship between the forearms and the travelling plate).

4 Concept of New UWA Robot

For $\alpha = ArcTan(\frac{1}{\sqrt{2}}) \approx 35.26$ degrees the motor axes are orthogonal to each other. Such configurations require more detailed examination. Also, when β=60 degrees motor axes become parallel to the opposite sides of the base triangle. For the purposes of this study, configurations that have α=35.26 degrees have been called Ortho-Parallel Robots. Because the motor axes are orthogonal when α=35.26 degrees and they are parallel to the sides of the base triangle when β=60 degrees, this configuration — known as a New University of Western Australia Robot – NUWAR [Miller, 1998], see Figure 3 — was chosen for a more detailed analysis.

The calculations showed that the workspace of NUWAR is 9.4% larger than the workspace of the Delta, assuming all dimensions being the same. NUWAR's

workspace has a larger cross section in the region closest to the baseplane ($z<0.35$ m), but a smaller cross section in the other half of the workspace ($z>0.35$ m). Hence this robot would be more suitable for applications where a larger workspace is required close to the baseplane.

The results of numerical simulations formed a basis for a construction of a prototype, which commenced in May 1998. The robot will be actuated by three high torque BSM100B-2250 AC servo motors. The amplifiers chosen are DBSC 1110 AAAW AC Servo Drives. The control of the robot will be executed by PMAC-Lite four-axis controller. These equipment has been supplied by Australian Baldor [Baldor, 1997].

Additional refinement in the design of NUWAR's kinematic arrangement was the replacement of the ball joints connecting the parallelograms to the arms and the travelling plate, by pin joints [Tsumaki et al., 1998; Miller, 1998], see Figure 4. This improvement allows for more robust mechanism, with higher torsional rigidity. Also, the manufacturing of the NUWAR mechanism employing pin joints is simpler.

The maximum acceleration achievable by NUWAR will be about **600 m/s^2**. Thus our robot will become the fastest in the world.

5 Conclusions and Discussion

This paper presents the results of workspace analysis of Delta-type parallel robots, leading to the development of the concept of the New UWA Robot – NUWAR. Maintaining all dimensions, and therefore the size of the robot, unchanged, the influence of motor axes orientation (angles α and β, Figure 2) on robot's workspace volume and shape was researched. Our results show that the configuration of the New University of Western Australia Robot – NUWAR is advantageous over the Delta configuration in terms of workspace volume. The shape of the workspace of NUWAR is beneficial for applications involving manipulations relatively close to the baseplane.

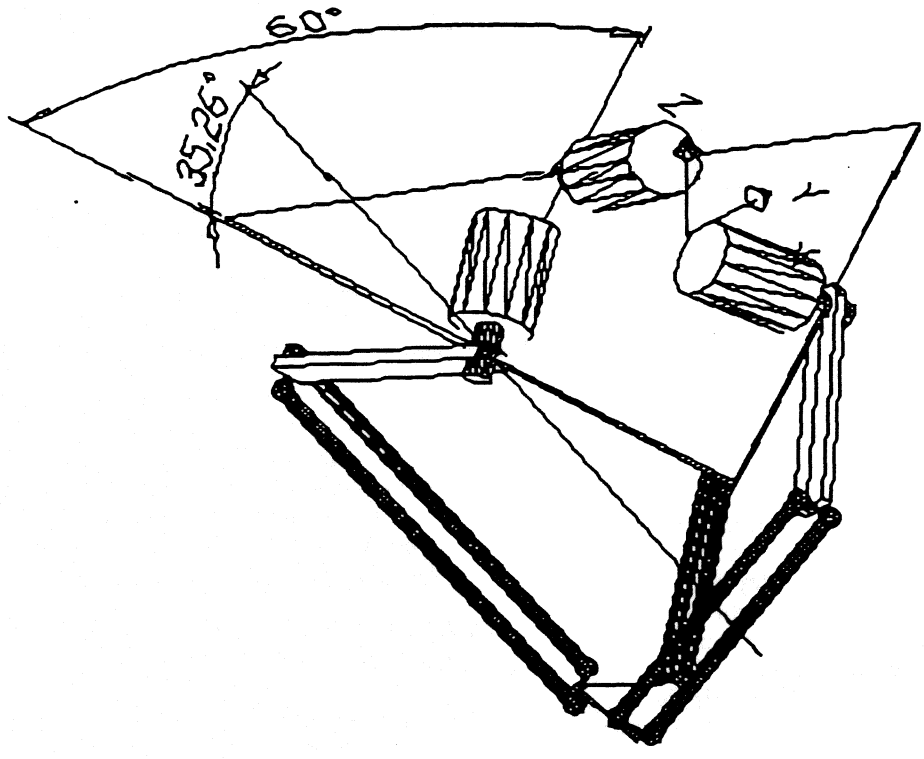

Figure 3. New University of Western Australia Robot – NUWAR: α=35.26 and β=60 degrees

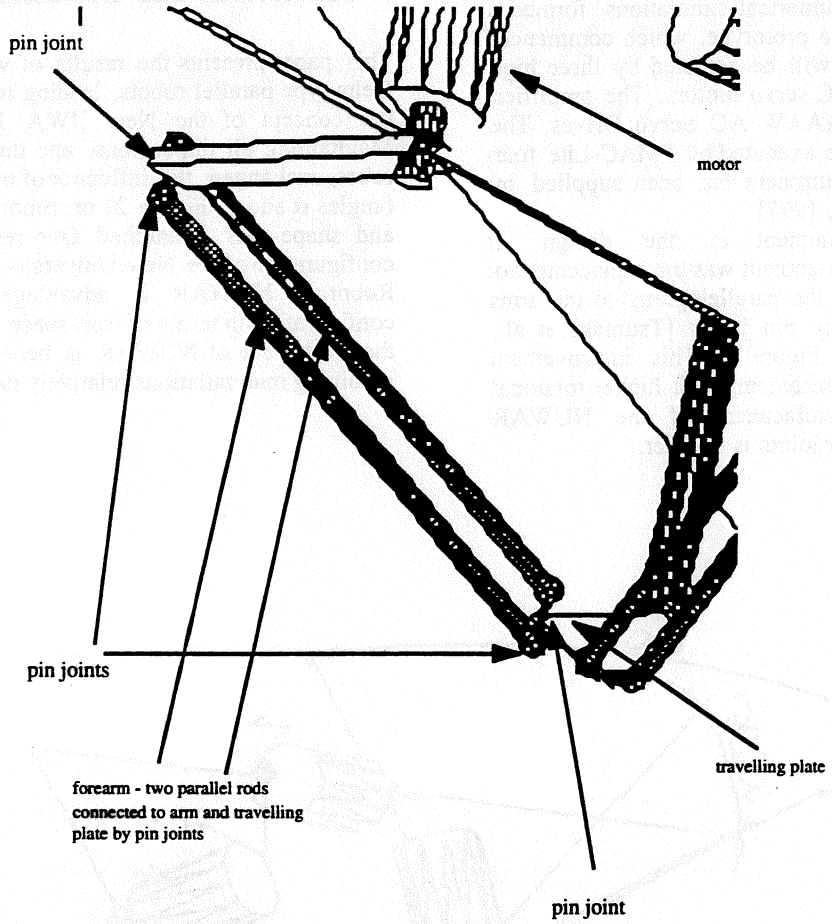

Figure 4. NUWAR invention - additional refinement: ball joints replaced by single degree of freedom pin joints

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