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OPTIMIZATION OF JOINTS AND LINKS IN PLANAR PARALLEL ROBOT MECHANISMS

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ABSTRACT

Now a day's Robotic automation becomes a major driving force in modern industrial developments. The parallel robots, also called hexapods or parallel kinematics machine (PKM) are closed- loop mechanisms presenting very good performance in term of accuracy, rigidity and ability to manipulate large load. This paper intends to present a comprehensive synthesis of the Design and optimization of a high Speed Planar Parallel robot. Applications for this type of robot include manufacturing and assembly where high speed and accuracy are required in a relatively small workspace. In present work robots are intended for pick-and-place applications that have a relatively large workspace. Although it was useful to know if certain robot configurations were inherently tension-able, the robot implementation would not be successful if the design parameters were not optimized properly. The purpose of the paper is to prevail the fundamental for the new approaches to robotics, however, where the emphasis is on understanding and exploiting the dynamics of interactions with the world, it makes sense to measure and analyze the systems as they are situated in the world.

Keyword: Parallel kinematics machine, RPR.

1. INTRODUCTION

Now a day's Robotic automation becomes a major driving force in modern industrial developments. The parallel robots, also called hexapods or parallel kinematics machine (PKM) are closed- loop mechanisms presenting very good performance in term of accuracy, rigidity and ability to manipulate large load. Parallel manipulators are robots that consist of separate serial chains that connect the fixed link to the end-effectors link. The following are potential advantages over serial robots: better stiffness and accuracy, lighter weight, greater load bearing, higher velocities and accelerations, and less powerful actuators. A major drawback of the parallel robot is reduced workspace. Parallel robotic devices were proposed by MacCallion and Pham (1979). Some configurations have been built and controlled (e.g. Sumpter and Soni, 1985). Numerous works analyze kinematics, dynamics, workspace and control of parallel manipulators (see Williams, 1988). Hunt (1983) conducted preliminary studies of various parallel robot configurations. Cox and Tesar (1981) compared the relative merits of serial and parallel robots. Industry always thrives for higher quality and more economical processes. Robotic automation has been the primary driving force for improving modern manufacturing processes. A fast and accurate pick-and-place operation is a desired robotic application for many industrial sectors. Typical pick-and-place applications such as packaging, assembly, and part sorting require manipulation of an object on a flat surface. It is a common practice to stack multiple planar manipulators together while using a conveyor to feed a matrix of objects in a direction normal to the manipulator workspace.

This approach usually saves precious manufacturing space in an industrial environment. In this work, a new type of 2D cable-based parallel manipulator is introduced that is intended for high-speed pick-and-place applications that require manipulation of light objects. The primary requirements for pick-and-place operations are high accuracy, high speed, and high repeatability. High accuracy can only be attained if the robot construction is stiff enough to suppress deformation; high speed, on the other hand is limited by the actuator power and the robot inertia. The most common industrial robotic manipulators nowadays are Cartesian tables and Articulated manipulators. These types of configuration independent motions from one link to another in a serial fashion; hence they are classed into the serial robot family. Due to the nature of the design, the robot actuator, or at least the power chain that is connected to the actuator must move with the manipulator. As a result, a serial robot trends to have a large moving inertia to one payload ratio regardless of the size of the actuator. A new type of robotic design, parallel mechanisms have emerged from recent robot developments. This type of robot is constructed by attaching multiple independently actuated kinematics chains to a mobile platform. Since the kinematics chains do not stack from one to another, any force that is applied to the mobile platform is distributed amongst multiple linkages. This electively increases the stiffness of the robot structure. Moreover, the actuators of each chain can be fixed on to a base, and they do not become part of the moving inertia. These two properties provide parallel mechanisms with an inherent advantage on stiffness and inertia over their serial counterparts. With the advantage of stiffness and low inertia, parallel mechanisms have quickly found their way into many high speed pick-and-place applications. Among which, the Delta configuration is arguably the most successful design in the last decade. Most of the recent parallel robot designs can achieve 150 cycles per minute. If the underlying principle of the success in high-speed pick-and-place robots is light and stiff, there must be other methods to improve robot performance by further reduction in moving inertia without compromising too much on structural stiffness. Work by Prof. Khajepour and Dr. Behzadipour, The fundamental design strategy is to improve the stiffness to inertia ratio by replacing rigid linkages of the kinematics chain with flexible cables. Mechanical cable, which is virtually mass less, possesses a relatively high mechanical strength under tension. The fundamental principle of this design approach is to replace the heavy linkages with cables. An additional advantage of using cables is that they can replace revolute joints, which are relatively costly and unreliable due to their limited life expectancy. Furthermore, there are several design issues that must be addressed when using cables in a mechanism.

2. CLASSIFICATION BY MECHANICAL STRUCTURE

The following is a popular way of classifying industrial robots according to the mechanical structure. Each has its own set of limitations and benefits. Mechanical structure is one of the important consideration when selection an industrial robotic arm for performing a particular task.

A) Cartesian Robot

Cartesian robot is form by 3 prismatic joints, whose axes are coincident with the X, Y and Z planes. Advantages: 3 linear axes, easy to visualize, rigid structure, easy to program.

Disadvantages: Can only reach front of itself, requires large floor space, axes hard to seal.

b) Gantry Robot

Cartesian coordinate robots with the horizontal member supported at both ends are sometimes called

Gantry robots.

c) Cylindrical Robot

Cylindrical robot is able to rotate along his main axes forming a cylindrical shape.

Advantages: 2 linear axes +1 rotating, can reach all around itself, reach and height axes rigid, rotational axis easy to seal.

Disadvantages: Can't reach above itself, base rotation axis as less rigid, linear axes is hard to seal, won't reach around obstacles.

d) Parallel Robot

Parallel robot constitutes two or more kinematics chains between the base and the platform where the end-effectors are located. Parallel robot is a complex mechanism, which is constituted by two or more kinematics chains between, the base and the platform where the end-effectors are located. Good examples are the flying simulator and 4-D attractions at Univ. Studios.

3. PERFORMANCE EVALUATION

Beside workspace, which is an important design criterion, transmission quality index is another important criterion. The transmission quality index couples velocity and force transmission properties of a parallel robot, i.e. power features [21]. Its definition runs:

$$T = \frac{\|E\|^2}{\|J\| \cdot \|J^{-1}\|}$$

Where E is the unity matrix. T is between $0<T<1$; $T=0$ characterizes a singular pose, the optimal value is $T=1$ which at the same time stands for isotropy [22]. In isotropic configurations the Jacobian matrix has the condition number, as well as the determinant, equal to one and the robot performs very well with regard to its force and motion transmission capabilities. Let us present the most essential performance measures that are used in mechanical design of manipulators. Traditionally they are directly included in the design constraints/objectives to be satisfied or optimized throughout the prescribed workspace. However, in this paper each performance measure is preliminary converted in an alternative form that defines the workspace subset where the relevant criterion is higher/lower of the desired value.

3.1 Geometric and Kinematic Performances

In robot design, the manipulator architecture is usually defined outside of the main optimization loop and highly depends on an application target. Within the CAD system, this architecture is described as an assembly of the links/joints that is parameterized by the link lengths and the joint limits. This set of the parameters is sufficient for evaluating the basic geometric and kinematic specifications such as the workspace size, dexterity, velocity transmission, reachability, etc. Using this model, the workspace **W** may be generated in a straightforward way. It worth mentioning that, for parallel robots, the direct kinematics is usually non-trivial and an analytical solution do not exist in the general case (Merlet, 2006).

However, because the Jacobian varies throughout the workspace, it should be defined a global metric that is usually computed by averaging or by detecting the worst cases.

3.2 Elastic Performances

For parallel manipulators, elasticity is an essential performance measure since it is directly related to the Positioning accuracy and the payload capability. Mathematically, this benchmark is defined by the stiffness Matrix, which describes the relation between the linear/angular displacements of the end-effector (wrench) and the external forces/torques applied to the tool. It is obvious that the elasticity is highly dependent upon geometry, materials and link shapes that are completely defined within the CAD model. The stiffness matrix may be computed using three different methods: the Finite Element Analysis (FEA), the matrix structural analysis (SMA), and the virtual joint method (VJM) (Alici & Shirinzadeh, 2005). The first of them, FEA, is proved to be the most accurate and reliable but requires very high computational efforts for repeated 3D remeshing over the whole workspace. The second method, SMA, also incorporates the main ideas of the FEA, but operates with rather large structural elements that allow some reduction of

the computational expenses. And finally, the VJM method is based on the expansion of the traditional rigid model by adding the virtual joints (localized springs), which describe the elastic deformations of the links. It is the most efficient technique for the design optimization, which was recently enhanced by the authors to handle a case of the overconstrained manipulators (Pashkevich et al., 2008). Within this approach, the kinetostatic model that defines the differential kinematics and elasticity taking into account the active, passive and virtual joints, describes each ith kinematic chain of the manipulator.

4. THREE- RPR DESCRIPTION

The manipulator considered in this paper is symmetric and composed of three identical legs Connecting the fixed base to the end-effectors triangle as shown in Fig. 1. Each leg is of *RPR* design, with two passive revolute joints and an active prismatic joint in between. Each prismatic joint is an actively controlled pneumatic cylinder.

4.1 Kinematics

The 3-*RPR* kinematic diagram is given in Fig. 2. The three grounded passive revolute joints are located on the base triangle at *i A* and the three moving passive revolute joints are located on the moving triangle at *i C* , where 3 , 2 , 1 = *i* . The active prismatic joint variables are the total lengths *Li*, giving the length between passive revolute joints. The moving frame {*H*} is at the triangle centroid and the base frame {*B*} is shown in Fig. 2. The Cartesian variables are the triangle link pose $[x,y,\varphi]^T$. The Grubler mobility equation predicts this device has three degrees-of-freedom, by counting eight rigid links connected by nine one-*dof* joints. θ*i* are passive intermediate joint angles which are not required for hardware control, but which may be calculated for computer simulation and/or velocity and dynamics calculation.

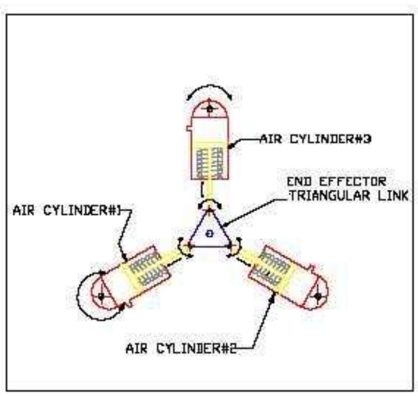

Figure 1. 3-RPR *Manipulator*

4.2 Workspace

Limited workspace is the principal disadvantage of parallel robots. Therefore, we are using a geometric method

(Williams, 1988) to determine the 3-*RPR* workspace and design the manipulator parameters to maximize the workspace. This effort is not complete, but the hardware has been built to allow for different ground revolute locations *i A* to evaluate workspace results in the future, constrained by the hand triangle link (which we can also change) and the prismatic joint limits.

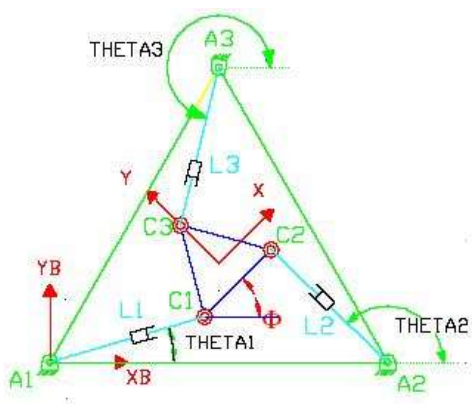

*Figure 2. 3-*RPR *Kinematic Diagram*

5. THREE- RPR DESIGN AND CONSTRUCTION

This section discusses the design and construction of 3-*RPR* hardware at Ohio University. The budget for this project was small, so the most important design specification was to make use of existing actuators, sensors, control elements, and I/O boards. Also, since most robotic projects at Ohio University make use of DC servomotors, it was desired to use pneumatic power for a change of pace. This dictated the use of existing pneumatic air cylinders (spring loaded to return to minimum joint length), linear variable displacement transducer (LVDT) length sensors, solenoid valves to regulate air flow to the cylinders, and a PC-based control system using Quanser Multi-Q I/O boards. The three *RPR* legs are identical, with three independent pneumatic cylinders and LVDTs across each. An oil-less air compressor is the pneumatic power source, providing 120 psi, regulated to a constant 60 psi which is delivered through a three-way hose coupling manifold to each solenoid valve to power the cylinders. Components which were procured included pneumatic plumbing elements, Delrin plastic for the hand triangle, link extensions, and ground fixtures, plus bolts for the passive revolute joints.The 3-*RPR* robot hardware is shown in Fig. 3. In Fig. 3 the pneumatic cylinders are on the bottom while the LVDTs are mounted parallel to the cylinders on top.

6. PERFORMANCE MEASURES

Let us present the most essential performance measures that are used in mechanical design of manipulators. Traditionally they are directly included in the design constraints/objectives to be satisfied or optimized throughout the prescribed workspace. However, in this paper each performance measure is preliminary converted in an alternative form that defines the workspace subset where the relevant criterion is higher/lower of the desired value.

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7. CONCLUSION

Parallel robotic manipulators present attractive solutions for innovative machine-tool architectures, which should insure high-speed and precision machining of large spectrum of materials. However, practical utilization of the potential benefits requires development of efficient optimization techniques, which should satisfy the computational speed and accuracy requirements of relevant CAD procedures. To response this challenge, the paper proposes an integrated approach to the design optimization of parallel manipulators.

The developed approach has been validated by a number of case studies, which focus on the design optimization of transnational parallel manipulators of the Orthoglide family. This paper intends to present a comprehensive synthesis of the Design and optimization of a high Speed Planar Parallel robot. Applications for this type of robot include manufacturing and assembly where high speed and accuracy are required in a relatively small workspace. In present work robots are intended for pick-and-place applications that have a relatively large workspace. Although it was useful to know if certain robot configurations were inherently tension-able, the robot implementation would not be successful if the design parameters were not optimized properly. The purpose of the paper is to prevail the fundamental for the new approaches to robotics, however, where the emphasis is on understanding and exploiting the dynamics of interactions with the world, it makes sense to measure and analyze the systems as they are situated in the world.

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