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## Recent Trends in Applications of Parallel Manipulators

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**ABSTRACT:** The rise in the demand for precision levels in the fields of manufacturing, medical science as well as space exploration equipment and experimental accuracy in laboratories, the applications of parallel manipulators have increased exponentially, both in terms of accuracy as well as variety. A parallel manipulator consists of a closed looped kinematic chain mechanism, which is linked by several independent kinematic chains to the end-effector. The focus of this paper is to realize the latest advancements of parallel manipulators in fields by exploring the applications: heliostat, surgical telemanipulator, dexterous hand, micro-vibration simulator and polymer made spatial parallel manipulator. The basic aspect of each application is explained and all of the applications included are only from 2015 onwards.

**KEYWORDS :** parallel manipulators; applications; heliostat; surgical telemanipulator; dexterous hand; micro-vibration simulator; polymer spatial manipulator.

### I. INTRODUCTION

Parallel manipulators have been in the limelight recently even though traditionally serial manipulators require large workspace and complicated maneuverability. The common problems with serial manipulators are that their cantilever structure makes them vulnerable to bending at heavy loads and vibration at higher speeds leading to lack of accuracy. In this paper, our focus is on the recent trends and applications of parallel manipulators in various fields. Also in applications demanding heavy load carrying capacity and accurate positioning[9-12], the parallel manipulators are the better than their serial counterparts and the recent applications points to the potential in this structure. Willard L. V. Polard [1] designed and patented the first industrial parallel robot. The development of parallel manipulators can began in early 1960s, when Stewart [2] designed and developed a platform manipulator for use as a flight simulator. Since 1980, there has been an increasing curiosity in the development of parallel manipulators. This paper highlights the recent potential applications of parallel manipulators including polymer based 3DOF machine, space micro-vibration simulation, an automatic 3-RPS parallel manipulator, a dexterous hand grasp using parallel manipulator & a surgical telemanipulator using parallel mechanism. The Hexapod machine tool is also one of the widely used parallel manipulators for various industries.

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## II. PARALLEL MANIPULATORS

For a parallel kinematic mechanism, the kinematic equations are considerably more complex due to the closed kinematic loops, than for an open kinematic structure which is used for serial manipulators. Parallel manipulators are closed loop manipulators. For development of high performance robots, imitation models are required for simulation and performance analysis. Any mechanical systems which compose of common conventional joints, traditional parallel manipulators suffered from precision errors due to backlash, hysteresis, and manufacturing errors in these joints. As opposite to serial manipulators, there can be utilization of un-actuated or passive joints. The presence of these passive joints and multi-DOF joints makes the kinematic analysis exponentially different from kinematic analysis of serial manipulators. Parallel robots are inbuilt more accurate than serial robots because their errors are averaged instead of being added cumulatively as a result of many parallel links and closed loop architecture. These parallel manipulators possess many intrinsic characteristics over serial manipulators, hence lot of applications are being developed currently as well as in near future in various fields.

Classification of Parallel Manipulators:

1. Symmetric
2. Planar
3. Spherical
4. Spatial

Symmetrical manipulators has number of legs equals to number of DOF, which is also equals to total the numbers of loops. A planar parallel manipulator is designed by two or more planar kinematic chains acting together on a common platform. Spherical manipulators make the end effectors movement according to controlled spherical motions. Especially, spatial parallel manipulators with DOF 4 and 5, attracted the attention of the researchers as well as the users. In the most of the research literatures, kinematic analysis is done by either kinematic constraint equations, screw theory method [3]. By using the inverse dynamics, the torques and forces of the actuated joints can be calculated and controlled for closed loops configurations of parallel architecture. As per the literature review, Euler Lagrange formulation is relatively costlier than Newton Euler approach for parallel manipulators

## III. APPLICATIONS

### 1) Heliostat:

The 3 legged 3-DOF parallel manipulator based heliostat proposed by R.B.AshithShyamet. al. [4] utilizes 3-RPS manipulator for each leg. (R: passive rotary joint, P: prismatic joint, S: passive spherical joint). The design parameters of the heliostat include consideration of wind speed and load, the base and top circumradii and the orientation angle of the base axis with local East direction. The base circumradius kept optimal as per the mirror size: 487mm for 2m x 2m, 877mm for 3m x 3m and 1755mm for 5m x 5m and the top circumradius for the same mirror sizes are 500, 900 and 1800 mm respectively.

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Fig. 1 Prototype of 3-RPS Heliostat [4]

The parallel manipulator consists of a linear actuator, DC motor, gear box and lead screw for each of the 3 legs. A proportional integral plus derivative (PID) control is established on a ATMEGA2560 micro-controller. A structural weight reduction of 15-60% is obtained progressively proportional to the mirror size.

### 2) Surgical Telemanipulator:

Surgical telemanipulators are developed with a motive to increase precision, eliminate human error and hygienic conditions both for surgeon and patient. Laparoscopic procedures require extreme accuracy, along with the challenges being lack of space and low range of vision. These high precision procedures require a remote centre of motion (RCM), which allows the instrument to have a rotational motion about a point inside patient's body.



Fig.2. Surgical Telemanipulator model design in Solidworks [5]

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The passive point fixation (RCM) method allows position control of end-effector as it concludes the forward and inverse kinematics of surgical manipulator. R.Trochimczuk [5] in his numerical analysis of 5 different designs of the telemanipulators, subjected to +50N and -50N on the end effectors concludes that for the same material (Stainless Steel), the accuracy of position control differs according to the configuration.

### 3) Dexterous Hand for 6-DOF Within-Hand Manipulation:

The mechanism proposed by Connor M. McCann and Aaron M. Dollar [6] which is based on 'hexapod' structure of spatial parallel manipulator. The design consists of 1 'grasp' actuator which is controlled through an underactuated differential mechanism which controls 6 paired prismatic actuators. The 'grasp' actuator is designed by converting Stewart platform parallel manipulator by exchanging the spherical joint connection to end actuators with fingerpad mounted spherical joint. The object grasped acts as parallel manipulator and torque is applied inwards to exert a normal force at each of the contact prismatic actuators.



Fig.3. Dexterous Hand 6-DOF Within-Hand Manipulator [6]

The extent of reconfiguration in translation motion of  $\pm 25$  mm and rotational motion of  $\pm 10$  degrees was achieved.

### 4) Space Micro-Vibration Simulator:

Spacecraft consists of different devices like reaction wheel assemblies (RWAs) and control momentum gyroscopes. These devices causes micro-vibrations while in orbit operations. Due to these vibrations the accuracy in positioning, stability and other performance indices for large calibre and high resolution optical loads are affected. To overcome this, ground testing is needed. To develop the micro-vibrations of optical load; design of parallel manipulator is proposed. [7] To control the accelerations, iterative control strategy based on transfer function is used. The parallel manipulator used consists of six legs and upper & lower platforms. Hinges are used to connect legs with both platforms. Upper hinges have 3 DOF and lower hinges have 2 DOF. The driving legs contain voice motor as its dynamic component. Sleeve is present to protect the motor and develop connection between spring pieces and motor.

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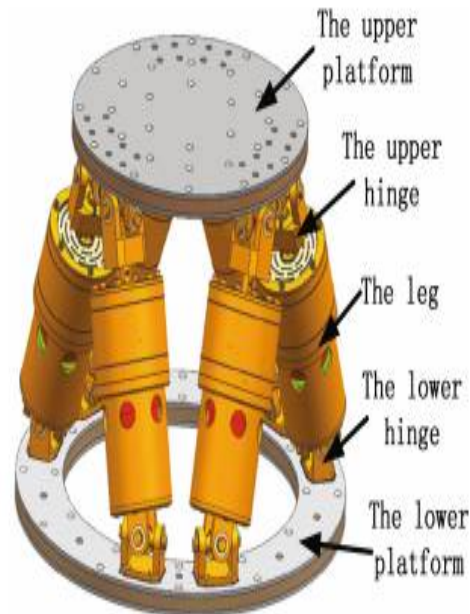


Fig. 4. Space Micro-Vibration Simulator [7]

Spring pieces are used to provide support to motors and legs. Spring is made of six sets of grooved arcs and number of connections is 6 between internal and periphery. The upper and lower platforms consist of three-layer structure. Middle layer is made of insulating phenolic resin and is connected to legs and other layers are made of steel. The hinges are used to connect upper and lower platforms to legs. Angular contact bearings are used and to sustain large axial force, bearing are designed back to backform. The bearing support is designed as one piece U-shaped structure.

### 5) Polymer made 3 DOF spatial parallel manipulator:

In his paper [8], author MikiHorie, so as to realize the functions equivalent to the functions of the spherical bearing which is commonly used in spatial mechanisms, a polymeric manufactured hinge with Hytrel, a material which has a high flexural fatigue resistance is tested. The mechanism used is used so as to measure positioning accuracy and repeatability which is of great significance in cell production and development processes. For this mechanism, four hemisphere concaves (HC) are used.

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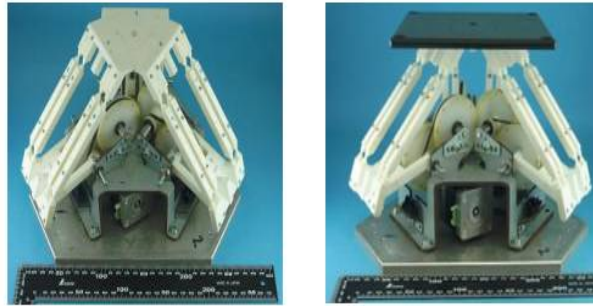


Fig. 5. Polymer made 3 DOF spatial parallel manipulator [8]

The coordinates of these four points are measured using three dimensional measuring machine. Polymer made planar hinges as well as polymer made spherical hinges are used. In his analysis, the positioning accuracy and repeatability of this parallel manipulator over conventional manipulators is revealed by numerical analysis.

### IV. CONCLUSION

Several parallel mechanisms have been developed and investigated in the last three decades. Automated welding, inspection, grinding, cutting as well as material handling, pipe fitting, firefighting robots, ship building, air craft maintenance, bridge construction, ship-to-ship cargo handling etc. are the various areas of applications. Numerous prototypes of innovative manipulators along with machine based parallel architecture have been developed. One of the primary features of parallel mechanisms like Stewart platform, hexapods, hexaglides, and delta robots realize suitable behavior for applications where high speed operation and precision makes important the dynamics of the system. Because of these advantages, with the applications of machines running at very high speed, mechatronics and parallel manipulators in medicine field has caught interest of several innovators for betterment of human-life. Deep-sea maintenance of oil and gas facilities can be improved in terms of precision and be more effective by implementation of parallel manipulators. A consistent and increased effort by researchers will help grow the capability, effectiveness and efficiency of various parallel robotics applications

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