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A Review: Parallel Robot in Robot Assisted Surgery

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Abstract

A parallel manipulator can be defined as closed kinematic chain, the end effector of which is connected to its base by a number of different linkages and together worked in parallel system. The Parallel robot provides precise positioning, high load carrying capacity, faster movement, higher bandwidth, high stiffness, stability and accuracy. These characteristics of parallel robot allow it to work better than serial manipulators. Robot assisted surgeries which conventionally used serial robots to perform surgeries occupy large operating room space, raising safety issues and also very expensive. Therefore, serial robots are now replaced by parallel robots which overcome all these difficulties and permit the relocation of the robot easily in a small workspace of the operating room to perform surgeries and provide high accuracy at low price. Hence, this paper demonstrates a review on the parallel robotic systems, its applications in medical field or in robot assisted surgeries and their corresponding technologies.

1. Introduction

Parallel robots have attracted the lot of attention now days due to its applications in different fields like industry, space, manufacturing, commercial use and especially in the medical science [1]. Parallel robots are classified according to the change in degree of freedom and by combining different kinematic chains, like 6-DOF Stewart [2] parallel robot is widely used. A large number of parallel mechanism systems have already been built and also in further research as they work with high accuracy, provide good stability, high load capacity, stiffness at low cost. Due to these advantages of parallel robot, it has become a new approach for the robot assisted surgeries and overcomes all the difficulties of serial structure robot which was the conventional method of performing surgeries. It helps the surgeons to perform accurate and delicate procedures safely in the small workspace of operating room [8]. There are other important features of parallel robot which make it the best for the surgeries; these are discussed below in detail. This paper presents the survey on the parallel robot and applications of parallel robot as robot assisted surgery, and also its comparison with the serial robot.

About Parallel Robot

A mechanical system that uses several computer-controlled serial chains to support a single platform, or end-effector termed as parallel manipulator. It means that the position of the end point of each linkage is independent of the position of the other linkages and the end effector of this linkage is connected to base by a number of separate and independent linkages working in parallel [4]. Parallel manipulators have kinematical structure and these are made of multiple closed kinematic loops. These kinematical loops are made with number of kinematical chains that connects a fixed base with the moving platform, where one joint in the chain is active, another are passive [5]. Serial manipulators are chosen as compared to Parallel manipulators in most of the case because of high position accuracy due to non-cumulative joint errors [6] and also their higher rigidity and higher load capacity make it better to use over the serial manipulators [5].

The parallel robots are further hard to optimize due to the complexity of direct kinematics and to the presence of singularities in the workspaces of robot [6]. The serial type of manipulators usually has larger workspace and greater dexterity than parallel manipulators [5]. These two is the disadvantages of parallel robot. The above survey indicates that the parallel robot possesses many characteristics that help to use it in various fields or there is lot of applications of parallel robot.

2. Applications of Parallel Robot

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Stewart published a paper in 1965 in which he proposed a six degree of freedom parallel platform as a flight simulator. That is parallel robots can be used as flight simulator and as pick and place robot [2]. The Stewart platform consists of 6 pods, 6 spherical joints and six universal joints with 6 degree of freedom as shown in **figure 1** [3]. The Gough Stewart mechanism later used in various applications in many industries like entertainment, aeronautics, health, surgery, and most recently machine tools [3].

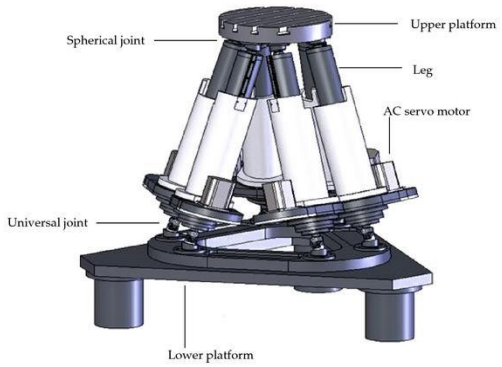

Fig: 1. Gough Stewart platform [3].

Parallel robots can be used for drilling, welding, tapping, assembly of printed circuit boards by giving greater accuracy, repeatability in limited workspace [1].Parallel robots also have interesting characteristics in the fields of micro-motion manipulators, remote centre compliance (RCC) devices, assembly, material handling, satellite antennas, and inspection of various sites and so on [1].

Now days, parallel robot has interesting applications in space and also in high laser operations. As parallel robot has light weight and consume less power, it can be used in laser operations [7].

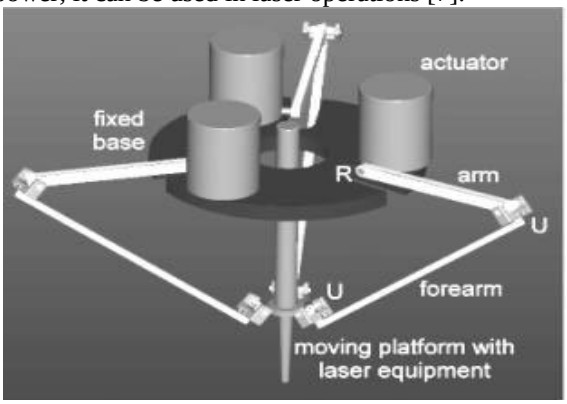

Fig: 2. parallel laser equipment [7].

The other applications are Cutting, Excavating and Grading, Shaping and Finishing, Lifting and Positioning, clean-up of disaster sites, access to remote areas, and manipulation of heavy payloads.

Inspite of all these applications, now days, the parallel manipulator are used in medical field. These are used in the surgeries of the humans.

This paper highlights the applications of parallel manipulators in medical science. But, before this, it is necessary to know about the Robot Assisted Surgery.

3. Robot Assisted Surgery (Ras)

Robotic assisted surgery also called computer-assisted surgery was developed for improving the abilities of surgeons carrying out open surgery. In RAS, surgeon uses the instruments via a direct tele-manipulator instead of moving the instrument with the hand. A telemanipulator has the robotic arms which carried out the necessary movement needed during the surgery of patient by using the end effector [4].

Fig: 3. Da Vinci Telerobotic Surgical System [9].

The advantages of RAS are that the surgeries can be performed easily with neatness, good accuracy, lesser incisions. It can reduce blood loss and provide faster healing time with less pain. In RAS, there is no need to stand throughout the surgery, thus do not tire as quickly [4].

There are certain disadvantages of RAS:

- higher procedure cost[4]
- To operate the system surgical training is needed.
- surgical robots are slow in assimilation in the operating room and not 100 % safe [8],
- these surgical medical robots occupy too much operating room space and also raise safety issues, [8]
- Surgeries become very expensive and also give poor positional accuracy [8].

These above drawbacks are overcome by using parallel robot in the robot assisted surgeries. The parallel robot that is directly placed on the patient anatomy is called “miniature robot”, thus this take less operating room space, give good positional

accuracy and the overall cost of the procedure is also less. The various types of surgeries using parallel robot are discussed below.

4. Parallel Robot In Medical Science

The applications of parallel robots in the medical science include neurosurgery, ENT, Ophthalmology, Spine surgery and orthopaedics for total knee and hip replacement surgery, 3D ultrasound imaging, robotic TMS, cardiopulmonary resuscitation, ankle rehabilitation etc. Some of the applications in detail are discussed.

Spine and Trauma surgery: In 2003, a new concept MARS (Miniature Robot for Surgical procedures) was introduced by Moshe et all [10], it is 6 DOF parallel manipulator based on positional accuracy, work volume, safety, proper orientation and also positioning of a hand held surgical tool in the vicinity of a rigid bony structure. The main advantages of the MARS include that it gives a proper guide by a surgical tool which can be easily operated by the surgeon. In 2005, Mukherjee and Rendsburg in their paper [11] also used parallel robot and proposed a surgeon-instructed, image-guided and robot assisted system for long bone fractures reduction.

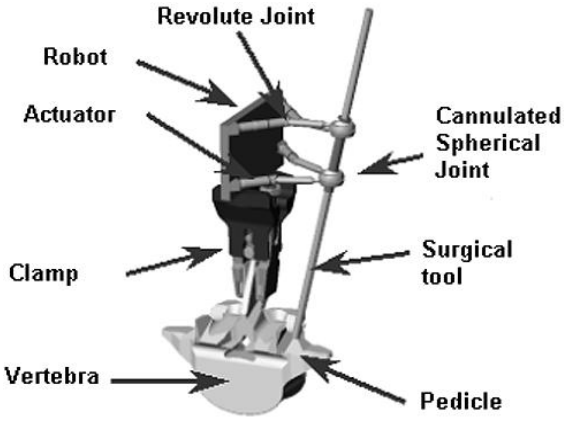

Fig: 4. A four DOF parallel bone-mounted robot. [10].

4.1 Parallel Ankle Rehabilitation Robot

Michael Girone presents a "Rutgers Ankle" Orthopaedic Rehabilitation system based on Stewart platform [12]. The "Rutgers Ankle" gave patients the ability to perform a variety of different exercises at their home. The parallel ankle rehabilitation robots were proposed according to the movement of the healthy ankle.

Then, in 2012, Parallel Ankle Rehabilitation Robot for Sprained Ankle Physiotherapy [13] was proposed and this designed ankle rehabilitation robot had the simple and compact structure, automatic adjustment function, which is suitable for patients on ankle rehabilitation training.

Fig: 5. The "Rutgers Ankle" Orthopaedic Rehabilitation System [12]

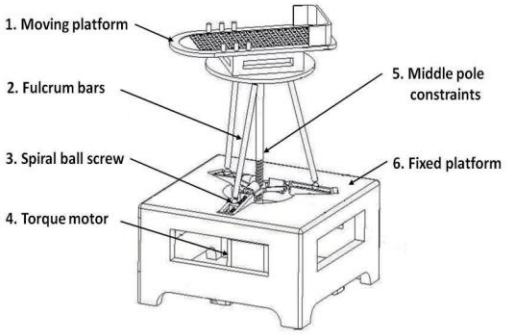

Fig: 6. Parallel ankle rehabilitation robot [13]

4.2 Cardiopulmonary Resuscitation (CPR)

Yangmin and Qingsong [14] proposed a parallel mechanism for compressing the chest of the patient and this robot is basically a 3-RRPaR TPM (translational parallel manipulator) which is one of the advanced types of DELTA parallel robot in cardiac arrest. This TPM has an advantage of more compact structure for medical applications in CPR and It also ease the workload of doctors and the risk in rescuing patients significantly i.e. Safety, workspace, workload are the main characteristics in designing of parallel robot.

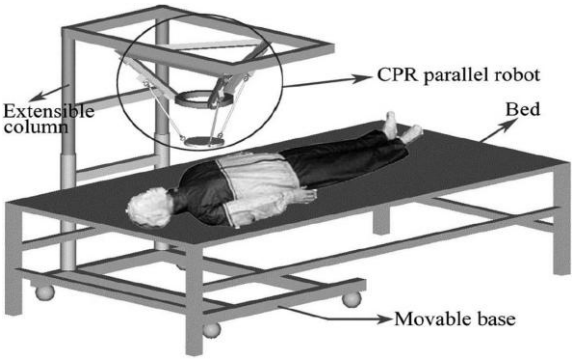

Fig: 7. Conceptual design of CPR operation [15].

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4.3 Micro parallel robot MIPS

Merlet proposed MIPS[16], a micro robot in 2001 which has parallel mechanical architecture of 3 DOF (1 translation and 2 orientations) which permits adequate positioning of a surgical tool and also offer high accuracy and load capability within small workspace. The only purpose to develop this robot is to provide accurate additional mobility at the tip of an endoscope to enlarge the field of MIPS application in inspection.

4.4 Automatic Bone Drilling Carriage for Stereotactic Neurosurgery

In stereotactic neurosurgical operation, improvement of the value of surgical procedure, precision, safety, low morbidity and transience are the main concern. The stereotactic frame is placed on the patients' head by the surgeons for the exact location. But the frames limit the instrument's access in the operating room and give the physical anxiety and psychological strain to the patient and also it is very time consuming process. Hence, a parallel surgical robot is proposed by Tsai and Hsu in 2004[17] for precise skull drilling in neurosurgical operation.

4.5 Parallel Robots applied to Robotic TMS

Transcranial magnetic stimulation (TMS) method can be used for modifying the activities of neurons in the head. There are various applications of robot guided TMS such as in the treadmill walking. Currently, Serial robots are used for the applications of TMS, but these robots provide less stiffness and the operating speed reduces to extent due to safety reasons as serial robots has high moving mass. The serial robots also take more workspace of the operation theatre, thus it bounds the performance. Therefore, Jong and Stienen in there paper [18] proposed a technique for the assessment and comparison of parallel manipulators during a particular task for safe human interface. And, on comparison Hexa robot gives the best safety features as it can overcome all the problems, it can combine high stiffness with small inertia and have potential for fast, safe and correct positioning essential for TMS.

4.6 Ophthalmic surgery

Nasseri et all [19] presented a 6 Degrees Of Freedom (DOF) hybrid parallel-serial mechanism which become advantageous for the surgeons to perform highly precision surgeries. The mechanism enables micro scale motions with high stiffness and sufficient output forces and can be easily integrated into standard biomedical environments and does not require any modification of conventional surgical tools.

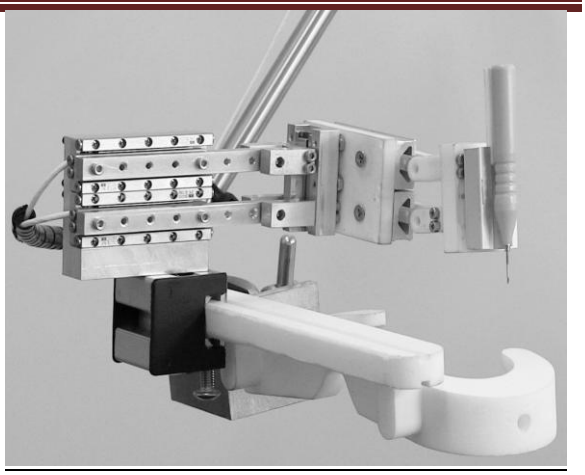

Fig: 8. 6DOF miniature robot designed for ophthalmic surgery

4.7 Animal Biopsies

For research purpose, small animal can sometimes be used and thus need of biopsy. For the biopsies of the small animal, manual needle insertion is used, but this process consumes time and most of the time difficult to operate animals due to their small sizes and also this process destroy animal cells and it can lead to trauma [20]. To require high accuracy positioning during needle insertion, Hwang and Bebek [20] developed a 5 degrees of freedom (DOF) Robotic-assisted autonomous needle insertion.

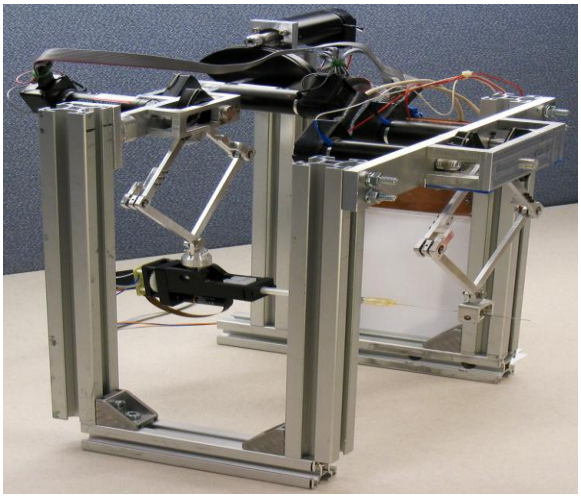

Fig: 9. Robot used on small animals

5. Conclusion

By above literature survey, it may be concluded that the characteristics of parallel robot make it efficient in robotic industry. With the development in parallel robot over the last few decades, parallel robots have become the new trend for Robot Assisted Surgeries and several structural mechanisms have

been investigated for different surgeries. It overcomes all the difficulties related to the conventional method of the surgeries get immense change in the medical field. Parallel robots have still in current state of research for the laparoscopic surgery, vitreo-retinal surgeries, knee replacement surgeries, endoscopic spine surgery etc. With the continuous effort of the researchers, parallel robot applications will grow more in other fields also like in mining, inspection, cargo handling, space applications etc.

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