

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 7, July 2015

A Brief Review on Hybrid Robot

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ABSTRACT: During the last few years, the number of research and development projects aimed at building hybrid robot has been increasing at a rapid rate. In this paper, a brief review on hybrid robot is presented. The main motivation for using hybrid robots and various applications of hybrid robots are discussed. Both published research papers and registered patents on hybrid robots are described. Various analysis performed on hybrid robot is also discussed. At last some of the challenging problems in the field of the hybrid manipulator, which are of research interest in the immediate future, are also discussed.

KEYWORDS: Hybrid Robot, Dynamics, Kinematics, Workspace Control

I. INTRODUCTION

There is rapid development of robot technology and thus more and more applications for robots are designed with different configuration. This paper is concerned of hybrid robot, applications of which have been increasing at a rapid rate.

Serial manipulators are made of a series of links and joints that connect the base to the end-effectors, and are capable of achieving large workspace. Serial robots have the advantages of large workspace, high dexterity and maneuverability, but there disadvantages are obvious. The enormous workspace leads to safety problems such as collision between the robot and the surrounding environment and a large area is consumed at the work table. Low payload to weight ratio and low stiffness leads to the high moving mass makes the robot's movement uneasy. The accumulated errors of the links lead to the low position accuracy. Moreover, the large size and high power consumption of the robot results in its high costs. Thus, serial robot is inappropriate for tasks requiring either the manipulation of heavy loads or a good positioning accuracy.

Parallel manipulators, such as the Stewart Platform [1], are robotic mechanisms which are composed of a set of parallel limbs, connecting the base plate to the moving plate, and they are able to achieve high stiffness and high force-to-weight ratio. This property makes parallel mechanisms an excellent option for high loads applications. The most important disadvantage of parallel manipulators is their restricted workspace. Parallel manipulators have limited workspace with respect to their serial counterparts. However, they have inherent advantages in terms of rigidity, high payload capacity, high velocity and high precision.

To balance the positioning accuracy and workspace, a hybrid robot is used. Some researchers have designed manipulators that present a compromise between the high rigidity of parallel manipulators and the extended workspace of serial manipulators. Many different types of hybrid robots have been investigated [2, 3, 4].

Thus a hybrid type manipulation system is a combination of closed-chain and open-chain mechanisms or it is a sequence of parallel mechanisms. Hybrid robots have drawn continuous interest in both industry and academia in the machine tool/robot sectors since the 1990s because of their potentially desirable fast dynamic performance, rigidity, and acceptable accuracy.

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II. APPLICATION OF HYBRID ROBOT

Hybrid robot has taken its place in Medical robot technology which is on one of the most thriving and the fastest developing research fields. Robot-assisted surgery has the advantage of reducing surgeons' hand tremor, decreasing post-operative complications, reducing patients' pains, and increasing operation dexterity inside the patients' body. Let's have bird's eye view on development of hybrid robot technology for surgery.

P. L. Yen [5] presented Cartesian parallel mechanism as the key module of the constructed knee surgical robot. In the constructed robot, the limited workspace and high rigidity of Cartesian parallel manipulator provide the surgical robot with enhanced safety and high cutting accuracy. S. Bruni [6] presented the design of a portable robot that can be easily handled in the surgical room, the robot presents a hybrid structure that permits to realize in a simple way the different milling bone cut planes to implant the prosthesis into the knee patient. T. Wang [7] presented a hybrid robot for lung cancer cryosurgery. Can Tang [8] presented kinematics study on the 7-DOF (degree of freedom) hybrid robot in minimally invasive surgery. R. Ye [9] presented 6 DOF robot for femur fracture reduction surgery. During such surgery, both patient and surgeon are exposed to a great amount of radiation, which is harmful to their health. Computer assisted orthopedic surgery is a less invasive approach for its ability to reduce the usage of image intensifier. W. Wei [10] in his Ph.D Work designed high-precision hybrid robotic systems with application for ophthalmic micro-surgery. D. Liu [11] presented 9 degrees of freedom hybrid robot for CT-Guided Surgery. Simulative clinical experiment showed that the locating precision of the hybrid robot reaches 1.08mm which can meet the requirement of CT-Guided Surgery. Z. Fan [12] presented study on recently developed 9-DOF hybrid robot for thoracoabdominal percutaneous cryosurgery.

Over and above the medical application the hybrid type robot can also be used in a window glass mounting, panel fixing, engine installing by gripper changing and so on. H. S. Choi [13] proposed a mechanism of hybrid type robot for construction works. A. Burisch [14] presented parallel hybrid micro SCARA robot for high precision assembly which had a base area of less than 150 x 150 mm² would position small workpieces with a mass of up to 50 g with a repeatability of better than 1 μ m. In the literature [15], study on Hybrid robot, which is used for multi-tasking machining processes such as milling, drilling, deburring and grinding is also available. Also study on Hybrid robot [16], which is used for reconditioning of mould and die tools is available.

III. PATENTS ON HYBRID ROBOT

D. L. Brenholt [17] Patent no. 4693663, 1987 presented a hybrid robot used for industrial applications comprises an articulated arm assembly pivoted to a turntable assembly mounted for rotation on a base assembly. L. J. Stocco [18] Patent no. 6047610, 2000 presented a six degree of freedom structure forming a robotic manipulator, consisting of two five-bar linkages set on rotatable base linkages; the output points of the five bar linkages are attached to a rigid payload platform by universal joints respectively. R. Gaunt [19] Patent no. US6543740B2, 2003 presented the mechanism which is a hybrid design that provides motion in six degree of freedom by arranging two, distinct, three degrees-of-freedom mechanism in series. The positioned comprising a base plate, a first plate mounted on the base plate by a first mechanical linkage, a first actuator arrangement for moving the first plate, a second plate mounted on the first plate by a second mechanical linkage, a second actuator arrangement for moving the second plate, and a holder attached to the second plate for mounting the object. W. E. Tobey [20] Patent No. US2008/0302200A1, 2008 presented an intelligent modular hybrid robot arm system which is usable with mobile robots and is applicable to stationary industrial arms. The intelligent modular hybrid robot arm system can manage its energy use, stores the arm in a compact shape and uses a central support tube offering unobstructed arm access to all sectors of its working envelope. G. Parnell [21] Patent no. US7474072B1, 2009 presented a case packing robot comprising a two dimensional articulated robot suspended from the top of a Cartesian Gantry-type frame enclosure. N. Simaan [22] Patent No. US2010/0331858A1, 2010 presented system, device and methods for robot assisted microsurgical stenting. Here parallel robot provides positioning of the serial robot over the operative area of the patient to perform surgical operating. N. Simaan [23] Patent No. US2010/0010504A1, 2010 presented systems, devices and methods for surgery on a hollow anatomically suspended organ. This hybrid-robot has at least two robotic arms

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attached to a frame releasably attached to a patient's head; wherein the at least two robotic arms each have a parallel robot and a serial robot; and wherein the serial robot includes a tube housing a cannula. P. B. Tzvi [24] Patent no. US2011/0073387A1, 2011 presents a hybrid mobile robot which includes a base link and a second link. The base link has a drive system and is adapted to function as a traction device and a turret. The second link is attached to the base link at a first joint. The second link has a drive system and is adapted to function as a traction device and to be deployed for manipulation.

IV. RESEARCH TRENDS ON HYBRID ROBOT

No of research papers are reported in the literature on Hybrid Robot. Here, brief ideas on few of them are presented.

Kinematics

In the literature, kinematic (forward and inverse) analysis performed on Hybrid robot used for various applications [3,9,16] are reported. Y. Diao[25] presented kinematic analysis of hybrid surgical robot. The Denavit-Hartenberg(D-H) method combining with successive rotation transformation was adopted to build the mathematical model for forward kinematics problem. The approach of geometry method combined with algebra method was proposed to solve the inverse kinematics problem. C. Tang[8] used ST(spinor theory) which is name as METM(Multi-layer exponential transformation method) for kinematics analysis of the Seven-DOF hybrid robot used in minimally invasive surgery. They found general method for robot modeling - traditional D-H Method, which is based on homogeneous transformation, has its limitations. One is that it cannot represent rigid-body movement as a whole, so it results in singularity by introducing local coordinates; at the same time, geometric description with homogeneous transformation for rigid-body movement is complex and is not convenient to implement. For hybrid robot, especially for hybrid redundant robot, traditional D-H Method for kinematics modeling cannot solve the problem. The ST for solving the problem of the forward kinematics is simpler than the traditional D-H parameter method because the former does not need to set up the link-rod coordinate system. The introduction of the ST in robot motion control is convenient to the kinematics modeling. T. Uchiyama[26] presented forward and inverse kinematic calculation methods based on "off-line teaching" for five-DOF parallel-serial hybrid robot. They proposed continuous path control algorithm, prototype robot is tested and for verification positioning test and pose test is carried out, result of which confirmed use of proposed methods.

Kinematic calibration

Accuracy is an important issue in the development of the robot, and can essentially be improved by kinematic calibration. T. Huang [27] presented the kinematic calibration of a 3-DOF parallel mechanism using a Double-Ball-Bar (DBB) system. The mechanism forms the main body of a 5-DOF reconfigurable hybrid robot named TriVariant that is a modified version of the Tricept, achieved by integrating one of its three active limbs into the passive one.

Dynamics

Various researchers had shown their interest to perform dynamic analysis of hybrid robot. It is found that R. A. Freeman[28], M. Sklar [29], P. L. Yen[5] who have used the principle of D'Alembert with the equivalent tree structure of the closed structure, and G. B. Chung [30] has calculated at first the local dynamics of each module with respect to the independent joint coordinates and then the dynamics of the hybrid robot is calculated by using the concept of the virtual joints that are attached to the base of each module. These methods are difficult to apply for robots having a big number of modules. Q. Ibrahim [31] presented recursive solutions method for obtaining the inverse and direct dynamic models of hybrid robots which are constructed by serially connected non-redundant parallel modules. J. H. Kyung [15] presented a dynamic analysis of a hybrid serial-parallel robot using generalized coordinate partitioning algorithm suggested by Wehage [32]. In order to derive the dynamics of serial-parallel wheeled mobile robot S. Ali [33] divided robot into two parts, i.e. the serial arm and the integrated platform together with the star-triangle parallel platform. They used a combined Newton-Euler and Lagrangian formulation to derive system dynamics model. H. Mohammadipanah [34] also used Iterative Newton-Euler and Lagrange dynamic formulation for their inverse dynamic analysis. M. Lacagnina [35] used the natural orthogonal complement method for development of dynamics equations.

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Kinematics and dynamics through Simulation

Y. Li [36] presented a six-leg-wheel hybrid mobile robot, which was designed to move under uneven terrains. The dynamic simulation model of the six-leg-wheel hybrid mobile robot was built using ADAMS software. The kinematic and dynamic characteristic simulation analysis were presented. These characteristics includes the displacement, velocity and acceleration of each part of the robot and driving torque of joints, contact force and torque between the wheels with ground and the ability of obstacle negotiation.

Mechanical design

P. B. Tzvi [37] presented new mechanical design paradigm for robot which is based on hybridization of the mobile platform and manipulator arm as one entity for robot locomotion as well as manipulation. Presented design provide solution to various issues related to design of mobile robots operating on rough terrain and in hazardous environments as well as in man-made urbanized indoor and outdoor environments. The mechanical design was analyzed with a virtual prototype that was developed with MSC ADAMS software. The simulation was used to study the robot's enhanced mobility characteristics through animations of different possible tasks that require various locomotion and manipulation capabilities. The design was optimized by defining suitable and optimal operating parameters including weight optimization and proper component selection.

C. C. Phipps [38] presented a design of bipedal planar robot that complements its walking and climbing capabilities with rolling. Rolling capabilities are provided by an innovative morphology, without the need for additional resources beyond those required by walking and climbing. They presented the design of this robot, the development of a quasi-static rolling controller, and a comparison of experimentally obtained speed and energy data for walking versus rolling locomotion. They show that rolling can significantly improve energy efficiency over walking—as much as a factor of 5.5. They also demonstrate the ability to roll up slopes and roll over obstacles.

In the era of global competitiveness there is large fluctuation in product demands and increasing product variety. To survive, in this aggressive environment, manufacturing system and/or facilities are required to possess reconfigurability. This is the ability to rapidly change in structure as well as in hardware and software components in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or in regulatory requirements. To meet such an objective Tian Huang[39,40] presented work on conceptual design and dimensional synthesis of reconfigurable hybrid robot.

Workspace of hybrid robot

T. Tanev [41] presented an algorithm for the determination of the workspace of a new type of hybrid manipulation system is proposed in the paper. This algorithm is based on the obtained closed form solution of the inverse kinematic problem for the hybrid manipulator. The determined reachable and dexterous workspaces are graphically presented. The knowledge of the workspace is important for the design, trajectory planning and application of the manipulators.

V. FUTURE RESEARCH INTEREST

Some of the challenging problems in the field of the hybrid manipulator, which are of research interest in the immediate future, are as follows.

- 1) Study of the dynamic behaviour of the hybrid manipulator through extensive simulation and analytical / numerical tools
- 2) Identification of possibilities of specialized control strategies, which will take advantage of the hybrid parallel structure of the manipulator and will offer, improved performance
- 3) Identification of various application which take advantages of the hybrid structure
- 4) Derivation of theoretical results regarding controllability and observability issues
- 5) A detailed description of the workspace
- 6) Workspace synthesis for the hybrid manipulator
- 7) Optimal kinematic synthesis of the hybrid manipulator for well-conditioned workspace
- 8) Optimal structural synthesis of the hybrid manipulator for minimum joint actuations
- 9) Fault tolerant control of hybrid robot

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- 10) Fault accommodation through reconfiguration of hybrid robot
- 11) Jerk study of a hybrid robot

VI. CONCLUSION

It is concluded from this paper that over recent years hybrid robots have drawn continuous interest in both industry and academia in the machine tool/robot sectors because of their potentially desirable fast dynamic performance, rigidity, and acceptable accuracy. Numbers of applications are reported in the literature, one may concentrate on any one of the above listed relatively untouched topic and dig out more area where hybrid robot can prove itself as better option.

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