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Obstacle Avoidance in Cable Driven Parallel Robot

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Abstract: -- **In this paper, obstacle avoidance algorithm for four cables is driven parallel robot is proposed considering the industrial environment where it can be used as pick and place operation. The four cables have been used to move the end effector in working space. The movement of the end effector is achieved by winding and unwinding the cables with help of Stepper motors in our case. Keeping positive tension in cables, Cable driven parallel robot moves straight in the direction of goal point or final destination until the obstacle detected in the path. Sensors are used to detect an obstacle in the path. With the help of algorithm, it avoids the obstacle and continues the straight line movement to goal afterwards. The path of the end effector is considered for jerk-free smooth motion. The algorithm presented in this paper ensures collision free path for Cable driven parallel robot when path exists. This algorithm further can be extended for industrial cranes and quad copters.**

Keywords: Collision avoidance algorithm, obstacle avoidance, parallel wire robot, Wire driven robot.

I. INTRODUCTION

Cable driven parallel robot (CDPR) is manipulator using cables as a link member; the actuation of link length is controlled by either changing length of cable or the changing location of the end point of the cable. CDPR is also known as Wire driven parallel robot. Parallel robots can be used in many applications as the many researchers pointed out. Cable-driven robots can be used for various applications, such as cleanup of disaster sites, access to remote locations, manipulation of heavy payloads, and pick and place tasks. Cables are much lighter than rigid linkages of a serial or parallel robot, and very long cables can be used without making the mechanism massive. As a result, the end-effector of a cable robot can achieve high accelerations and velocities and work in a very large workspace for example a stadium. These types of robots have a moving platform or end-effector and a base structure, which are connected by multiple parallel cables. The end-effector is operated by actuators like stepper motors that can release or retract cables by winding and unwinding it. Cable-driven parallel robots have advantage of large workspace compared to conventional parallel robots with linkages. Besides that, they have lighter structures, which give interesting dynamic properties, transportability in most cases, high payload weight ratio, and cheaper construction. Design, workspace analysis and Path planning are different for cable driven parallel robots because of the fact that cables can only pull the end effector and can't push it. So we have to take care that there is positive tension in all cables.

Cable-driven robots can be classified as "fully constrained" and "under-constrained". In the first case, the position and orientation of the end-effector can be completely determined as a function of the cable's lengths. In the second case of cable-driven robot, the pose of the end-effector is no completely determined by the cable's lengths. It depends on the presence of gravity. To have a fully controlled motion the necessary but not sufficient condition for a mobile platform with n degrees of freedom (DOFs) is considering at least m = n + 1 cables. This forms the workspace of cable robots which is defined as a region in space where the end-effector is able to exert the required force and moment vectors to the surroundings while all cables are in tension. Workspace and controllability of cable robots can be enhanced by adding cables to structure of the robot. We studied the problem of collision free trajectory planning in this paper for cable-driven robots. Collision free trajectory or path planning is an important issue in robotics. Lots of research has been done in Path planning with collision avoidance for the case of serial and mobile robots, but it is not well developed for the case of parallel robots. More focus is given to singularity avoidance instead of both singularity and obstacle avoidance in case of cable driven parallel robots. There are mainly two methods for path generation; Global methods and local methods. Global methods consists two stages. In first stage, spatial representation of the free space of the robot can be done with the help of sampling methods like grid sampling, random sampling. In the second stage the solution to path finding is obtained using artificial intelligence method. This method guarantee to find a solution if one exists but it needs long time for computation.

Local methods are more suitable for real time path planning. In this type of method, the robot is supposed not to know its environment in advance and it discovers obstacles n of robot's end effector. For each when it moves towards the goal. In the case of parallel robots, path-planning needs to consider avoidance of singularities. Singularities are configurations in which the robot becomes uncontrollable. They are hazardous and must be avoided. Paths should be planned in the force feasible workspace.

In this paper, we give results for a path planning in the force feasible workspace for a 4 cable driven robot by considering obstacles within its workspace. In the next part, a kinematic and static analysis is presented, which is necessary for path planning. Then we proposed the method that is used for collision avoidance.

II. LITERATURE REVIEW

Samir Lahouar et al.[1] proposed a path planning method for collision avoidance of cable driven parallel robot that is used for serial robots. Simulation is done on the robotics oriented software SMAR.An algorithm is presented to detect the collision between the robot and the obstacle.Although the path obtained between the initial and final poses may not be the shortest possible one, it guarantees finding a path, when it exists. L. Barbazza et al.[2] introduces a generic model of CDPR with movable anchor points on the end effector. The possibility to change the configuration of the cables in the end effector is the promising way to avoid collision. It is the case of cable driven parallel robot is used for pick and place applications in industrial environments. Results shows that a trajectory designed to find an optimum tradeoff between movement time and smoothness allows the CDPR to achive values of acceleration and velocity nearer to maximum allowable values. Bingtuan Gao et al.[3] presents a cable-driven flexible parallel robot with low motion noise to mimic a human neck. The cables serve as the muscles around the human neck to drive the robot. The inverse position and statics analysis were simulated in MATLAB. The optimization results show that it's better to place the cables near the upper bound and numeric implementation shows that the translation workspace of the robot is an inverted cone.

Ebubekir Yasar et al.[4] created an algorithm and used it to determine a path away from obstacles. Many different shaped obstacles with the help of intelligent objects that are created using object oriented programming (OOP) techniques. one of object oriented programming language Delphi is used for obstacle modelling. With the help of this developed algorithm not only the probable paths but also finding the shortest, safest and fastest path is possible. Han Yuan et al.[5] paper focuses on the vibration analysis of Cable-Driven Parallel Robots (CDPRs). This paper focused on a dynamic stiffness analysis where the cable vibrations, the end-effector vibrations, and their coupling are taken into account. Experimental analyses are carried out on a large-dimension 6-DOF suspended CDPR driven by 8 cables. The dynamic behaviour of the cables is derived using Lagrangian approach in conjunction with the Dynamic Stiffness Matrix method. Abdul muttalib et al.[6] introduced a novel method for robot navigation in dynamic environments, referred to as visibility binary tree algorithm. The performance is compared with three different algorithms for path planning. These three different approaches are Voronoi diagrams, Vis Bug and TangentBug algorithms. It has same performance in the global knowledge scenario and better performance when information on the obstacle locations is limited.

Paul Bosscher et al.[7] proposed a technology of Contour crafting which is a relatively new layered fabrication technology that enables automated construction of whole structures. The system proposed here consists of a mobile contour crafting platform driven by a translational cable-suspended robot. In order to investigate the workspace of this robot, example geometry was chosen and the workspace generated numerically using MATLAB. Based on this workspace analysis, it was concluded that the frame of the robot only needs to be slightly larger than the building being constructed.

Volkan Sezer et al.[8] designed a novel obstacle avoidance method is and applied to an experimental autonomous ground vehicle system. The Follow the Gap method is based on the construction of a gap array around the vehicle and calculation of the best heading angle for heading the robot into the centre of the maximum gap around, while simultaneously considering the goal point. Before the real tests of the algorithm, a simulation model is prepared using the Matlab/Simulink environment. Gap center angle formulation enables the robot to head to the center of the maximum gap around which results in safe trajectories.

Jason Pusey et al.[9] attempt to tackle some aspects of optimal design of a 6DOF cable robot by addressing the variations of the workspace volume. A program was created in Matlab for workspace analysis of cable suspended robots. The program inputs include the connection points of the base and moving platform. In this study, it appears that for any geometry the largest workspace volume occurs when the MP is the same size as the BP. The $\gamma = 0$ geometry has the largest workspace as well as the highest GCI of any other γ value for the same orientations.

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Ghasem Abbasnejad et al.[10] Gait training or gait rehabilitation is the process of learning how to walk and is applied to patients who suffer from gait dis- orders. A method based on PSO was used to determine the radius of a circular zone in which the wrench-closure configuration of the robot is guaranteed for a given range of orientations of the end-effector. Any external wrench on the target limb can be balanced using cables for all poses of the limb near to the trajectory in the gait cycle.

Alireza Alikhani et al.[11] presented the design and analysis about the synthesis of the robot as well as the sizing of the actuators and cables. A geometrical approach is used to represent the capability of the end-effector for applying forces and moments. Geometrical approach translated the design conditions into the geometrical inclusion of a sphere in a convex polyhedron and design equations of the cable forces and actuator torque were found.

Manfred Hiller et al.[12] analyses parallel manipulator under the aspects workspace, forward kinematics and trajectory planning.Trajectory planning must face a number of constraints, including workspace limitations, actuator and tendon limits, as well as smooth motion constraints. This type of CDPR allows the handling of heavy loads with high acceleration and low energy consumption. A major problem is to find acceptable force distributions in the tendons which can be solved by nonlinear optimization algorithm.

Jingli Du et al.[13] presents a dynamic model for cable-driven parallel manipulators with cables of slowly time varying length. This paper shows that it is necessary to take into consideration the cable dynamics for manipulators of long-span cables. The appropriate number of nodes for a cable to be divided is still a key problem to be further investigated.

Bin Zi et al.[14] addresses the cooperative problems in terms of localization, obstacle avoidance planning and automatic levelling control for a cable parallel robot for multiple mobile cranes (CPRMCs). The three-dimensional grid map method is utilized to plot the environment map based on the operation environment model. The four-point collaborative levelling method is adopted for automatic levelling control for the platform of the CPRMCs with PID controller. The results demonstrated that the automatic levelling control performance has been remarkably improved by applying the proposed collaborative levelling approach.

III. A 4 CABLE DRIVEN PARALLEL ROBOT

A 4 cable driven parallel robot has been designed and built at MEFGI, Rajkot. It is made of a mechanical structure, a controller, a PC for programming, end-effectors.

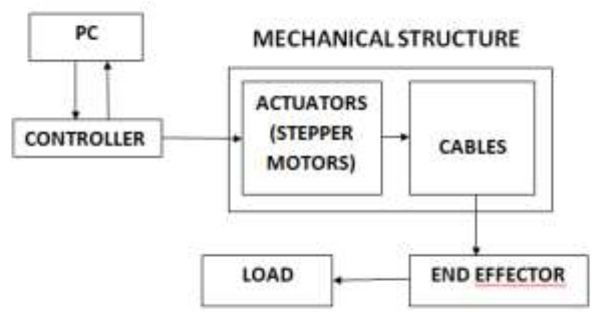

Fig 1 A scheme for the design of cable-driven parallel manipulators

The 4 cable driven parallel robot has been designed to be used for both spatial and planar motions. Because of the 4 cables, the robot can operate as an under constrained system or a fully constrained one, when spatial or planar applications are considered, respectively. This robot therefore contains the end-effector or base plate connected by 4 cables which are operated by the stepper motors. These four stepper motors are fixed in the top four corners of the structure. SMPS is used to supply power to these stepper motors. Arduino microcontroller is used controlling the motion of motors. Sensors were placed at the end effector for sensing the obstacle. Sensors give the feedback to controller and accordingly decision is taken by it. Such a type of robot exhibits mainly two types of different behaviors: (1) planar motion with 3 DOFs and 1 degree of redundancy (that is fully constrained motion in a plane); (2) spatial motion with 4 DOFs and no redundancy. In a spatial application 4 of the 6 DOFs can be controlled, another wrenches) and configuration of the end-effector, and the last DOF (the rotation about a line connecting the end-effector connection points) cannot be controlled. The planar configuration of the 4 cable robot can be used for applications such as pick and place operations or window washing; the latter can be used as a crane for lifting and moving heavy loads such as trusses.

IV. KINEMATICS

In the case of serial manipulator it easier to use forward kinematics while in the case of parallel robots inverse kinematics can be easily applied. In forward kinematics you can determine the pose of the end effector from known inputs angles. The transformation matrix is useful in representing Forward kinematics while inverse kinematics makes use of the kinematics equation to determine joint parameter that provides a desired position. We know the pose required and accordingly input angles and joint variables are modified.

V. PATH-PLANNING PROCEDURE

We suggest adapting path planning fundamentals and methods those are used for serial robots. This method is based on the switching between the two searching modes. The first one is called a depth search mode, which is operated when the robot is far from obstacles, and it moves toward its goal. The second one is known as a width search mode, which is in operation when the robot is near an obstacle and this allows it to search the best way to avoid an obstacle. Although a grid is needed, it is not necessary to construct it before beginning path-planning. Collision is checked only for those nodes which are included in the search path.

In the case of serial robots the configuration space is used with this method because it is easier than planning in the workspace. This is no longer justified in the case of parallel robots since the Forward kinematics problem is more difficult than the Inverse kinematic problem. That's why we propose to search for the trajectory in the workspace.

We explain the method by using a point robot evolving in the plane in the presence of obstacles. Then, we discuss necessary changes in order to get a collision free path in the force feasible workspace of a 4 cable driven parallel robot.

The planar case for a point robot

In order to explain the algorithm we use an example of a planar point robot which acts in presence of obstacles. Since there is no obstacle near the starting position, the depth mode is used in order to evolve towards the goal until position I is reached. Then, the width mode is used in order to find the best path to avoid the obstacle.

1. Depth mode

In this case, i.e. the robot is far from the obstacle, at each node the surrounding nodes are generated and they all point to the parent node. It will generate the proximity nodes nearby and then choose the nearest node to the goal.

2. Width mode

The width mode is activated when the search algorithm is Forced to choose a node that is farther from the goal than the investigated node. If at some node I, the nearest node to the goal is inside the obstacle, at this point a queue is made to contain all the candidate nodes of the two possible paths. This queue allows investigating turn by turn the two paths and ensures finding a solution when it exists. The queue is accessed in a "First in First out (FIFO)" basis.

3. Path generation

The generated final path at the end of the search phase is made using a backward propagation by starting at node F (finish node) then selecting its parent, until node S (starting node) is reached. It is interesting to note that the retained path does not contain all nodes, even though these nodes were used in the search process. This fact could be explained by noticing that a node is the parent of another node in the generation process. Therefore, during the backward process we jump directly from that node to its parent node. This shows that even though some nodes were visited by the search algorithm they are not necessarily in the final path, which allows us to shorten the path when possible. However, one can notice that the obtained path is not the shortest possible path between S and F. This result could be expected, since our proposed method is not a global one and hence does not guarantee the shortest path. However, our proposed method does guarantee finding a path, when it exists, no matter how cluttered the environment is.

Case of the 4-cable-driven manipulator

The above-mentioned method was used to plan the motion of the mobile platform of the 4-cable-driven parallel manipulator on a collision and singularity free path. Besides the problem of the collision of the platform with obstacles, one has to check that all the cables have positive tensions and they are not colliding with any external obstacle. To solve this problem we propose a method which is able to detect collisions between a cable and an object. Singularity is checked by performing a test on the pose of the mobile platform while moving from one point to another. If one pose presents a collision or a singularity, the algorithm will consider that point as a collision and will avoid it through the same procedure as it uses to avoid an obstacle.

The procedure given in above Section is applied in the case of the 4 cable driven robot by specifying the given angle set equal to 0, and the step size of the grid d(step size). The algorithm then starts by building the different nodes next to the initial node by incrementing each coordinate by the distance d. The nodes obtained are then checked for the nearest one to the goal, which is then checked for collision. If there is no risk of collision the nearest node is selected using the depth mode. If, however, a collision is detected in the nearest node the width mode is triggered to look for other alternatives. The procedure described for the point robot in Section is followed until a feasible path is found. In the general case, the flowchart of the algorithm is shown in Fig.

Collision detection among the mobile platform and other objects

In order to detect collisions among the mobile platform and other objects in the workspace, a distance calculation

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algorithm can be implemented. The method is an iterative process based on Rosen's minimization. One point inside each object is chosen, then on each step two points are found in the boundary of the object and in the direction minimizing

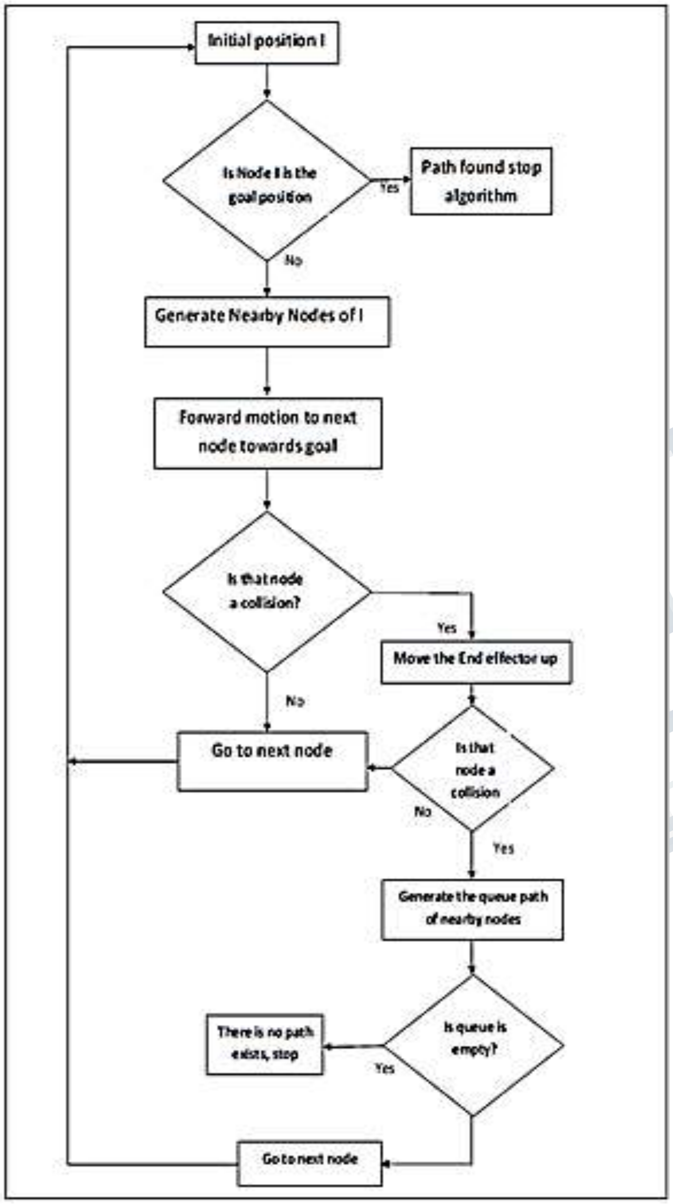

Fig 2 Flowchart of the path-planning algorithm

the distance. The process is stopped when the minimum distance is reached. In most cases this is achieved in three or four steps. This algorithm deals with polyhedrons only, but this is not a limitation since any shape can be approximated by a combination of polyhedrons. This algorithm is used together with the constraint method in order to accelerate the collision detection process.

Based on the distance calculation between the mobile platform and any object in the workspace, constraints are generated for one pose and the collision is detected by checking these constraints for all poses that are near that pose. This combination of methods makes collision detection fast enough to be used in real time applications.

Collision detection among cables and other objects in the workspace

We propose a new method in order to detect collisions among cables and objects in the workspace. The cable here is modeled by a segment defined by the two extreme points. The method we propose is fast and simple, since it checks collisions among convex polyhedrons and segments.

In the case of cable-driven parallel manipulators, problems Occur when there is no positive tension in one or more cables. This is due to the fact that cables can only pull the end-effector; they cannot push it. These configurations can be avoided by keeping the end-effector in feasible poses. Simulation and experimental results of a case study In order to evaluate the efficiency of the proposed method, we have done some experiments. All the simulations were performed with the robotic-oriented software to which a module has been added to detect collisions among cables and other objects. We also added a module that performs path-planning as an implementation of the proposed algorithm. Configuration A corresponds to the initial pose of the mobile Platform. In particular, an experimental test was carried out with the prototype in order to replicate the computed solutions These lengths are used in order to generate the program uploaded to the controller of the 4 cable robot. In order to show how cable collisions are avoided, a task was simulated where the cables are too close to an obstacle at the initial pose. The results of this task are shown. The mobile platform first goes up and then it bypasses the obstacle. At this stage the mobile platform goes down to its final pose.

VI. CONCLUSION

A method of path-planning for parallel robots has been used to generate paths for cable-driven parallel manipulators, in order to avoid collisions and singularity. The method deals with collisions that might occur between the mobile platform and the obstacles in the environment. In order to cope with the cable-cable and cable-obstacle collisions, a new fast collision detection method between cables and objects has been proposed. The robot uses a straight line path to go to the goal, as long as there is no risk of collision. When an obstacle is detected, the method goes around that obstacle in order to find the best way to avoid it. For the tested tasks, each simulation took less than one second. Once a path is found, a generated program is uploaded to the robot controller. Some simulation and experimental results are shown where the generated collision free trajectories for a 4 cable robot in presence of an obstacle in the workspace are presented. Although the obtained path is not the shortest possible one between the initial and the final poses, it does guarantee, however, finding a path when one exists, no matter how cluttered the environment is.

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