ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Cable Tensions Optimization in Cable Driven Parallel Robot for 3D structural printing

Suad Abdul Kareem Alhaj Mustafa and Bashar El-Khasawneh
Mechanical Engineering dept, Khalifa University, Abu Dhabi, UAE

Abstract - A new kind of large scale, suspended cable driven parallel robots (CDPR) is proposed in this paper as a potential substitute for conventional 3D building printing methods. In terms of workspace, usability, and power usage, the proposed CDPR outperforms the competition. To find the robot's optimum reconfiguration, a comprehensive approach for solving a nonlinear optimization problem is suggested. Various limitations and success expectations are discussed, as well as critical issues.

Index Terms - CDPR, Optimization, LP, PsP, tension

INTRODUCTION

In this study, four cables suspended CDPR are going to be demonstrated, the platform with dimensions 80X80X6 meters during transporting an end effector of weight (250kg). Thus, the CDPR will be analyzed in different cases through the test position and tension variating in each cable. The most well-known approach to this type of problem is to select the best solution from a set of alternatives, such as applying mathematical optimization techniques to produce a desired result or answer. In the world of robotics cable, such a topic is extremely important and largely researchable. Linear programming (LP), pseudoinverse programming (PsP), quadratic programming (QP), heuristic and nonlinear optimization routines are examples of relevant approaches. It is largely determined by the optimization approach used, as well as the robot and controller's behavior.
This paper first addresses the modelling of sag cable, constructing the relation between cable tension and the geometry of cable geometry. Then after selecting the number of cables to be used, a model of static equilibrium of end effector is derived. This problem is then treated using minimization of the Euclidean norm of the cable. Finally, the optimal tension distribution was solved in the end effector surface.

LITERATURE REVIEW

A. Literature Review

First, Robotics is the science for studying any multiple degrees of freedom (DOF) device that are programed in order to have a variety of tasks. It is a highly interdisciplinary arena with decades of study leading to a wide range of applications in a variety of areas and disciplines, including those outside of science and engineering. Robots can be classified in a variety of forms. [Sridhar, 2015]. One of the distinctions is by classifying it relying on the manner of linking and arranging the manipulator.

In this research, we intend to choose 4 cables in order to get 3 DOF CDPR for simplicity. Once the basic parameter (m) the degree of freedom was set and (n) the cables number that drive the platform was chosen, then the design of geometry problem includes the determination of the best cable positions that moves the end effector in the base frame, the cables connection points on the movable platform, and the connection of cable between the two ends.
To this end, the geometric two-phase model methodology is mostly applied and used. Inspired by [Hussein, 2018], by testing and studying the number of cables and the applicable way of connecting it between multiple methods of connecting the base and the end effector that are preselected geometry, it was the first portion this proposed methodology.
The paper organization will be as follow. The main focus is the mathematical model, static, and kinematic investigation that applied in this work. All the analysis methods are used to analyze the capability of the design in static and drive state as well, besides, its optimized solution.

B. Methodology

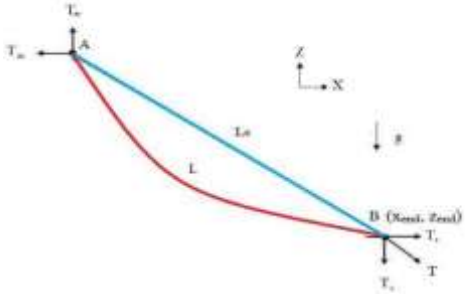
The strategy used in this part is to accomplish the paper goals that introduced as techniques by [Kozak, 2006]. The vital techniques and equations referenced in the previously mentioned works will be utilized after performing the essential coordinate system transformations.

PROBLEM FORMULATION

The mostly used equation of elastic catenary applied in different of engineering contexts . After skipping the derivation, it will look like below.

In the case of the CDPR where cable sagging has to be considered, the wrench matrix W is not only mobile end effector position dependent but it also effected by the cable geometry. Where in this case the cable geometry also affected by tension in the cable

In Figure 1, cable first end is A, B the second end attached with the end effector, L actual length between A and B, Le is a straight ine between A and B, g is the gravity acceleration, T the cable tension, Tx and Tz – the end effector side components of



coordinate x and z of the cable tension, Tpx and Tpz are the cable tension x and z components the first cable end, (xend, zend) the end effector cable side's coordinates.
The equations of the cable static displacement in catenary case after simplification are listed Where, ρ is the cable linear density.

| |

$$x = \frac{T_x}{\rho g}\left[\sinh^{-1}\left(\frac{T_z}{T_x}\right) - \sinh^{-1}\left(\frac{T_z - \rho g L}{T_x}\right)\right] \quad (1)$$

$$z = \frac{1}{\rho g}\left[\sqrt{T_x^{\,2} + T_z^{\,2}} \quad \sqrt{T_x^{\,2} + (T_z - \rho g L)^2}\right] \quad - \ (2)$$

A. Optimization methods

The fundamental principle behind the optimization approaches is to limit a truly significant target work while fulfilling the requirements. Mobile platform pose is supposed to be achievable, when a necessary position set is totally contained inside the arrangement of wrenches that the cables could be applied on the movable platform.The position can be characterized as the arrangement of wrenches that permits to adjust the absolute load of the mobile platform and the weight of the end-effector that characterized from maximum values of the cable tension as well as the admissible minimum values: t ≤ t ≤ t

$$\mathbf{T} \quad \geq \mathbf{0}$$

Where there are upper and lower limits for the tension requirement. Likewise, the tension should be positive value in case the end-effector have no pushing. The greatest tension should not go above the capacity of cable materials otherwise it will be damaged. In this work, the tension of cable "t" is considered as the optimized parameter in the procedure of geometry optimization. Solution set of a linear-inequalities system could be exemplified the convex polytope which represents the available wrench. All required variable inputs shown in the table I below.
TABLE I. SYSTEM PARAMETERS

Variable	Symbol	Value	Unit
Width	W	80	M
Length	L	80	M
Height	H	6	M
Mass of End Effector	M	250	Kg
Diameter of Cable	D	20	Mm
Cable density	ρ	7860	
Offset in y	□ y	6	M
Offset in x	□X	6	M

B. Cable Tension Optimization

The cable tension at a specific location of effector end was calculated. As referenced beforehand, this in case of various valid solutions. In order to find out a unique solution for such problem, it is treated as a minimization constrained problem. Thus, this statics problem is tackled as a linear programming issue with a purpose to minimize the tensions of cable. such problem is defined as demonstrated as follows:

Objective function:

$$\min \quad T$$

Subject to: $[A][T] + AF + m\,Ag = 0$

T **≤ T ≤ T**

$T \geq 0 \quad i = 1,2,3,4$

This problem is solved using Gurobi optimizer 9.1.0 on CORE i7 10th generation computer using the linear programming solver applies the "dual simplex algorithm", with the Lagrange multipliers that it returns. Furthermore, the pseudoinverse methods were additionally actualized utilizing the (pinv) order in MATLAB® to achieve a relative comparison. (Tpi)The cable tensions got utilizing such methods are indicated. Hence, toward the finish of this progression, four dynamic cable tensions are gotten.

RESULT AND CONCLUSION

Utilizing the code composed, in view of the optimization methods illustrated in the past paragraphs, simulations were carried out. Despite the made program works for the properties of cable besides the valid dimensions, the simulation results introduced here utilize the values for the variables inside table I above, Inverse Kinematic Programming was solved for four random poses, which included a nominal position of x, y and z simultaneously (0, 0, 0).Table II summarize the result of two optimization method, it's appeared that LP program is simpler even it takes longer time while PsP is less flexible, but it could give a close form solution.The stopping criteria for each method is the sum of squared function which must be less than sqrt of function tolerance. The relative norm of the gradient also must be less than Optimality Tolerance option.

TABLE II. SUMMARY COMARISON OF LP AND PSP

Linear Programming (LP)	Pseudoinverse Programming (PsP)
(Min □T)	(Min □(T)
Iterative method	Close form solution
overall cable tension is relatively small	Could be equal to Linear Program solution
High flexiblity	Low flexiblility
Possibilty of multiple solutions	One Solution
Cable density	ρ
Gurobi Optimizer	Matlab
No of itteration =17	No of itteration =13

REFERENCES

[1] Sridhar, D., & Williams, R. L. (2016, August). Kinematics and Statics Including Cable Sag for Large Cable-Suspended Robots.

[2] de Vasconcelos Segundo, E. H., Mariani, V. C., & dos Santos Coelho, L. (2019). Design of heat exchangers using Falcon Optimization Algorithm.

[3] Pott, A., Mütherich, H., Kraus, W., Schmidt, V., Miermeister, P., & Verl, A. (2013). IPAnema:
a family of cable-driven parallel robots for industrial applications..

[4] Chan, Y. P., Eden, J., Lau, D., & Oetomo, D. (2017). A Survey on Inverse Dynamics Solvers for Cable-Driven Parallel Robots..

[5] Williams, R. L., & Graf, E. (2020, August). Eight-Cable Robocrane Extension for NASA JSC ARGOS. I

[6] Hussein, H., Santos, J. C., & Gouttefarde, M. (2018, October). Geometric optimization of a large scale cdpr operating on a building facade.

[7] Cui, Z., Tang, X., Hou, S., & Sun, H. (2019). Non-iterative geometric method for cable-tension optimization of cable-driven parallel robots with 2 redundant cables.

[8] Kozak, K., Zhou, Q., & Wang, J. (2006). Static analysis of cable-driven manipulators with nonnegligible cable mass

[9] Song, D., Zhang, L., & Xue, F. (2018). Configuration optimization and a tension distribution algorithm for cable-driven parallel robots.

[10] Schenk, C., Masone, C., Miermeister, P., & Bülthoff, H. H. (2016, August). Modeling and analysis of cable vibrations for a cable-driven parallel robot.

[11] Abbasnejad, G., Yoon, J., & Lee, H. (2016). Optimum kinematic design of a planar cabledriven parallel robot with wrench-closure gait trajectory. Mechanism and Machine Theory, 99, 1-18.

[12] Chiacchio, P., Chiaverini, S., & Siciliano, B. (1996). Direct and inverse kinematics for coordinated motion tasks of a two-manipulator system.