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Development of a High Payload Cable-Driven Parallel Robot

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Abstract: A cable-driven parallel robot (CDPR) consists of elastic cables instead of rigid links. The lightweight of cables enables the CDPR applications for high payload, high speed and large workspace. However, the elongation of polymer cables can cause positioning error of the end-effector (EE) especially for heavy material handling application. In this paper, we propose an open loop load compensation algorithm to increase the relative accuracy of a CDPR. Since the force distribution of cables and cable lengths are different in different EE position, the elongation of cables will be different. Therefore, the algorithm are implemented with three different height (600, 800 and 1000mm) in straight line path. The payload of the robot system is 190kg. The experiment result shows that the root mean square error (RMSE) of EE position are 30.02mm for without load compensation and 0.65mm for with load compensation.

Keywords: Cable-driven parallel robot, high payload, load compensation. Position control.

1. INTRODUCTION

A cable-driven parallel robot (CDPR) consists of a number of cables instead of rigid links. Compare with traditional robots, lightweight cables make the robot have good candidate for high payload, high speed and large dimensional applications. Such as helicopter carrying a payload [1], large telescope [2], pick and place [3], high speed manipulation [4], and SkyCam [5].

To achieve high payload manipulation of the CDPR system that can be applied to the practical industrial robot system, we build up a high payload CDPR by using a polymer cable that can increase the high performance dynamics with low inertia effect. However, the viscoelasticity of cables deteriorates the position control accuracy due to elongated cables. In order to overcome the limitations, some previous researchers modeled the elasticity and hysteresis of cables [6, 7], we propose an open loop load compensation algorithm to increase the accuracy of a PCDPR.

The organization of this paper as follows. First, the general kinematic model of CDPR are shown in section 2. In section3 a developed high payload PCDPR is describes and its workspace are calculated using WireCenter software [8]. Finally, the control algorithm of the system is introduced and the effectiveness of proposed algorithm is demonstrated by experiment.

2. KINEMATICS OF CDPR

Inverse kinematics used to describes the joint variable with known end-effector (EE) pose. In Fig. 1, a general kinematic model of CDPR is given. Where index i (=1,…n) denotes the cable number. The geometric parameter A_i and B_i are cables attaching point on the fixed frame and EE, respectively. By applying the closure vector loop, the cable length vector $\mathbf{l}_i$ can be expressed as

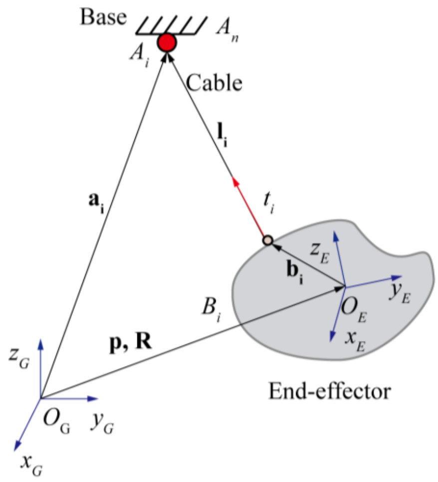

Fig. 1 Kinematic configuration of CDPR.

$$\mathbf{l}_i = \mathbf{a}_i - \mathbf{p} - \mathbf{R}\mathbf{b}_i\,, \tag{1}$$

where $\mathbf{a}_i$ is a constant vector between A_i and global coordinate $\{O_G\}$, $\mathbf{b}_i$ is a constant vector between B_i and EE coordinate $\{O_E\}$. **P** is the position vector of EE and **R** is rotation matrix of EE.

3. HIGH PAYLOAD PCDPR

3.1 Robot description

The developed high payload PCDPR is a type of suspended 6DOF robot which is consists of eight polyethylene Dyneema® cables (LIROS D-Pro 01505-0600, 6mm) as shown in Fig.2. Eight winch-motors and guiding pulleys are mounted on fixed bottom frame and top frame, respectively.

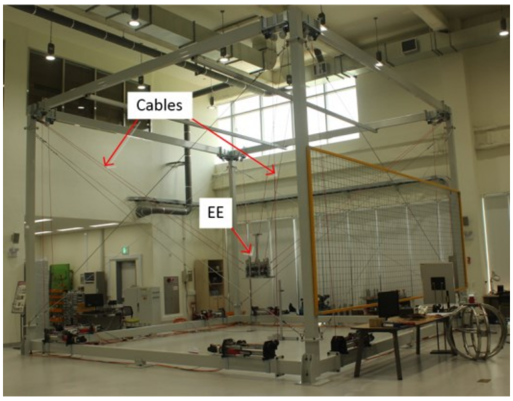

Fig. 2 Prototype of a high payload PCDPR.

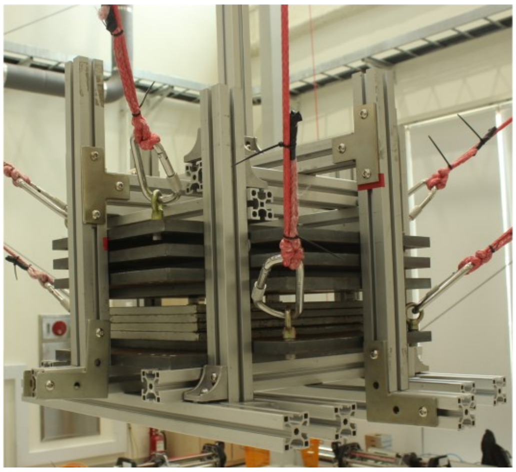

Fig. 3 End-effector of the prototype.

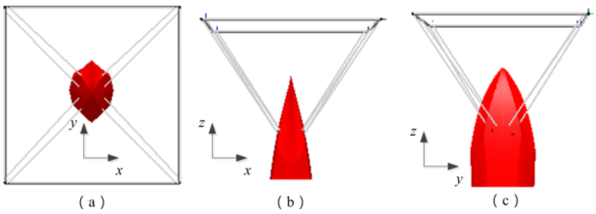

Fig. 4 Wrench feasible workspace in high payload CDPR: (a) x-y plane, (b) x-z plane, and (c) y-z plane

In order to perform a heavy material handling in large scale, the mass of EE is designed to be able to work up to 190kg. The power of current motor is 940W and maximum payload of our winch and pulley are 300kg. All the eight winches are equipped with force sensor and encoder to measure cable tensions and lengths in real time.

3.2 Workspace analysis

The workspace of CDPR depends on the geometrical parameters as well as the tension range of cables [9, 10]. In order to analysis the workspace of developed PCDPR, Wire Center is used to simulation tool and cable tension range are setting in 10N to 576N.

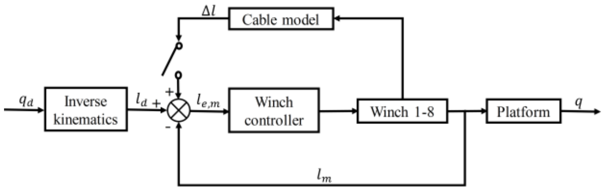

Fig. 5 Implemented control scheme.

Fig.4 show that the workspace of x-y plane is -1.092m to 1.089m, x-z plane is -1.456m to 1.453m and y-z plane is 0m to 2.851m. Obtained workspace is much smaller than the geometrical workspace. It is mainly caused by the limitation of the current motor power.

4. EXPERIMENTS

The elongation of cables cause the EE position control error in high payload CDPR. In this section, an open loop load compensation algorithm are developed.

4.1 Control scheme

To have good performance in position control, an open loop position control algorithm are developed. The control diagram show in Fig.5 include two parts. First part is general position control loop of CDPR, where desired cables length l_d are calculated by inverse kinematics and converted to desired motor output. The second part used to compensate the elongated cable lengths through the cable modeling.

4.2 Experiment results

Since the elongation of cables are different in different pose of EE, the algorithm are implemented with three different height (600, 800 and 1000mm) in straight line path. The motion is generated in z-direction with maximum speed of EE 1.2m/sec. Table 1 shows the experimental results of with and without load compensation. The maximum position error for the case of without compensation is 32.5mm but by using compensation, the error is 0.9mm. The RMSE of EE position for with and without compensation are 0.65mm and 30.02mm respectively. Fig.6 shows the experiment data of path C which are measured by optical tracking system (RMS ±0.3mm). Fig.7 show the changed cables length during the motion which measured by motor encoder. It can be seen that the amount of EE distance are compensated even though initial command (CMD) are same.

Table 1 Comparison of position control results of three different height.

	A	B	C
Command (mm)	600	800	1000
Without compensation (mm)	573.5	769.7	967.1
With compensation(mm)	600.6	799.7	999.1

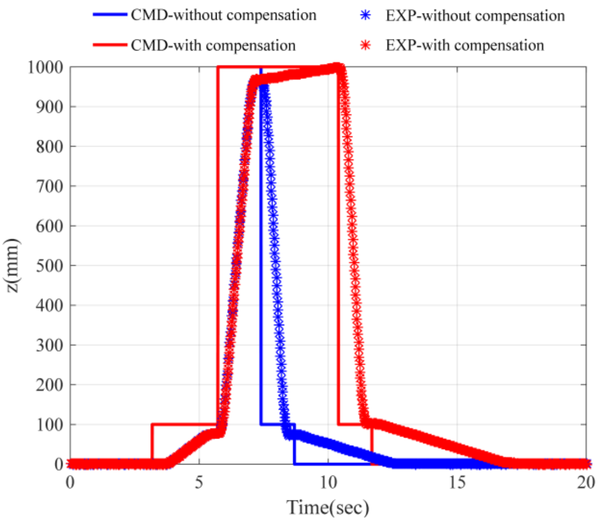

Fig. 6 Performance of with and without load compensation in path C.

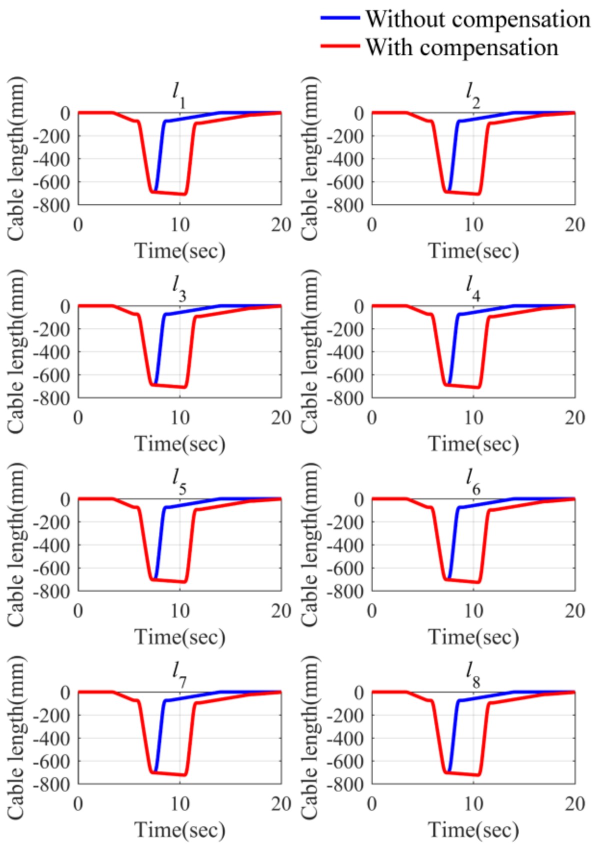

Fig. 7 Measurement of the change in cable length during the path C.

It should be noted that initial commands influence to the desired pose $\mathbf{q}_d$ only and additional cable length are compensated by model individually. Also, it is possible to control the speed of compensation in the range of motor specification.

5. CONCLUSION

In this paper, the development of high payload cable-driven parallel robot and a real-time load compensation algorithm is presented. The proposed algorithm is performed well in three different height of straight line path. Experiment result show that the relative accuracy of a PCDPR are increased obviously by compensating the elongation of cables.

In future work, the wide range of load compensation will be conducted with upgrade motors.

6. ACKNOWLGDEMENT

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