

Innovative Design of Continuous Variable Transmission Robot

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Abstract- The conventional motor driven robot is replaced now a day with continuous variable transmission (CVT) robots. The CVT Robots are safe during the man machine interaction and produce highly precise virtual surface, which controls the robot motion while performing the telerobotics operations. This work involved the design of 3 DOF CVT robots with construction and assembly of shoulder joints. The assembly and testing was done after machining of shoulder capstans and shafts. The angular stiffness for shoulder joints was found 18.08×10^3 N-m/rad while the starting torque found 1.3219N-m respectively.

Keywords- Robot; Continues variable transmission; Shoulder joints; Angular Stiffness; Starting torque

I. INTRODUCTION

Continuous transmission robots are the robots designed to present high quality constraints safely to human users [1]. The initial driving force behind the invention of robots was to meet the need for a robot that could interact safely with automobile assemblers. There are presently several different robots, but the defining feature common to all robots is the continuously variable transmission (CVT) used in place of traditional joints of cobot. The CVTs separates the robot's speed and direction kinematically. For example, the unicycle cobot [1] have one steered wheel rolling on a flat plane. The steered wheel is a CVT that controls the x and y axis transitional velocity ratio as a continuous function of the wheel's heading angle. The actuator, instead of controlling the rotational velocity of the wheel, is used to control the motion of the wheel.

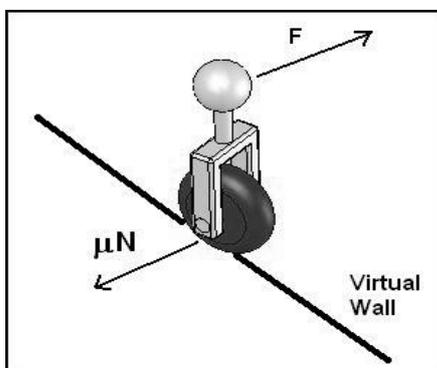


Fig. 1 Virtual Walls by Actuated Steering

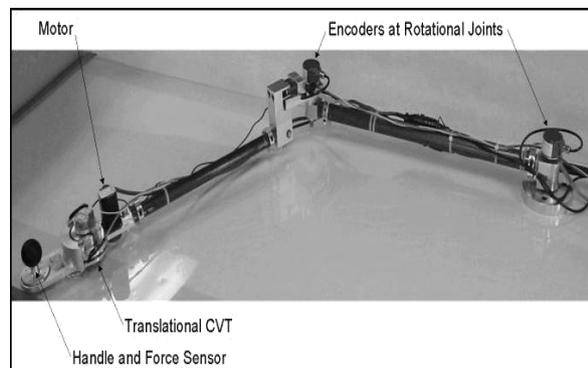


Fig. 2 UTLA

Fig. 1 shows this virtual wall created by actuated steering where upon reaching the virtual wall the wheel is steered to roll along the line of the virtual wall. The downward force and coefficient of friction determines the strength of the virtual wall. The Unicycle Two-Link Arm (UTLA) in fig. 2 was created for rehabilitation research. The UTLA is spring loaded at the second rotational joint to provide a constant down-force at the unicycle. The UTLA function in 3 types. A virtual caster mode senses the user's intended motion direction and steers the wheel to accommodate. The virtual path mode constrains the user to a specified path. The third mode, virtual wall mode, is a combination of the first 2 modes in which the user may move freely in certain areas but will be met with a virtual wall upon moving to the edge of the free movement area.

II. MECHANICAL DESIGN

2.1 CVT Robot arm

The CVT robot design has 3 spherical arms with a 3-DOF manipulator but facing problems with backlash and compliance. The CVT robot design aims to eliminate backlash through the use of cable transmissions while minimizing device weight and maintaining joint stiffness.

The CVT robot design, shown in fig. 3, will be mated to a new spherical CVT design currently in development. The previous spherical CVT design employed polyurethane in-line wheels of skate. These elastomeric wheels permit compliance and creep during the operation of CVT. This confirms that the CVT is propagated out to the endpoint of the manipulator to forming hard, high quality virtual constraints. The new there is metal-to-metal contact yielding a more controllable system with a compact design and a maximum sustainable input torque of 0.56 N-m; with a spherical CVT design.

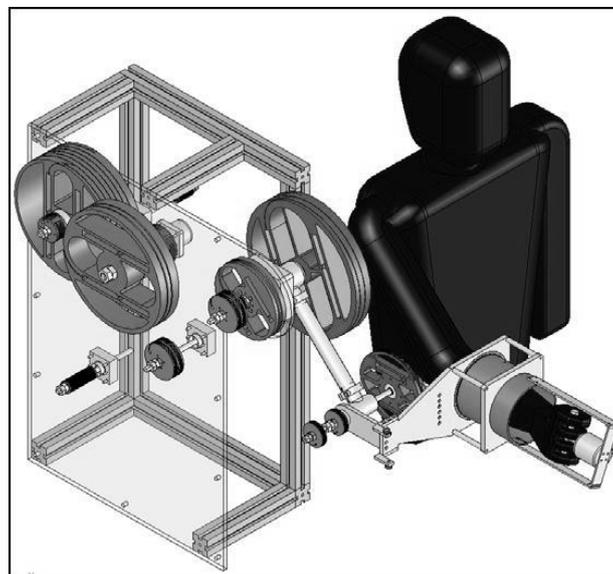


Fig. 3 CVT Robot

2.2 Transmission Ratio Design

2.2.1 Cable Transmissions

Cable transmission design in this paper is approached from 2 directions using method of iteration. The CVT on one end has a maximum slip torque of 0.67 N-m. Also on the other end the

end-effectors of the wearable cobot, is a maximum loading requirement reflecting that of the maximum torque a human can sustain. After initial calculations from one end of the device the calculations are iterated back and forth to find a set of variables that satisfy the requirements of a telerobotic master controller.

2.2.2 Design Parameters

In-lab tests were conducted to determine the maximum sustainable joint torques of a human-male for the shoulder and elbow joints including forearm rotation. Fig. 4 depicts the test conducted. The joint axis that was tested which represented by grey dots and the accompanying arrows depict the direction the arm was exerting force or torque. Experiments 9 and 10 tested forearm torque and are depicted in fig. 4 by a head-on view of the test results. Test is carried out on male graduate students 21-28 years of age. The experimental data in fig. 4 coincide with the numbers in table 1.

Sr. No.	Forearm Length (m)	Upper Arm Length (m)	1	2	3	4	5	6	7	8	9	10
1	0368	0.330	17.79	71.16	80.06	102.30	13	71.16	84.51	53.37	1.38	2.25
2	0.317	0.304	53.37	71.16	115.64	102.30	71.16	10.5	106.75	93.40	1.95	2.03
3	0.323	0.317	97.85	115.64	115.64	30	66.72	84.51	111.2	62.27	1.80	2.29
4	0.323	0.298	57.82	75.61	71.16	115.64	66.72	53.37	71.16	57.82	2.03	2.37

Table No. 1. Joint Force (Col. 1-8, N)/Torques (Col. 9-10, N-m)

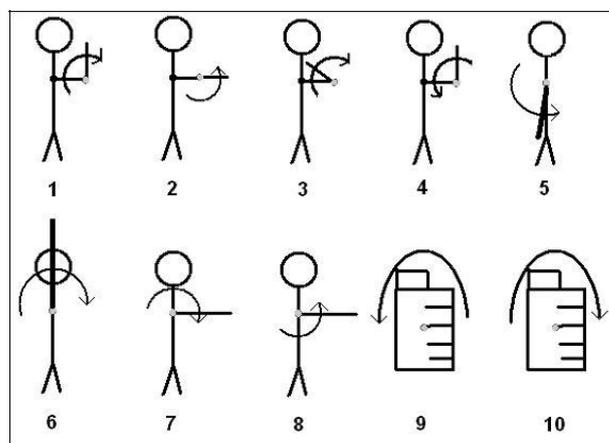


Fig.4 Experiment Configurations

2.3 Capstan Design and Cable Selection

2.3.1 Design Considerations

Joint stiffness and cobot arm weight are the main considerations during capstan design and cable selection to create a highly controllable master manipulator. It is kinematically advantageous to have a very light but very rigid mechanism to maintain the integrity of virtual constraints.

In the development of the Whole Arm Manipulator (WAM) the equation for mechanical torsional stiffness was derived [11]. Mechanical torsional stiffness k for a cable transmission is given by:

$$k = \frac{1}{2} * \frac{N^2 R^2 AE}{NL + x(1 - N)} \quad (2.1)$$

The variables in eqn. 2.1 are defined as follows. Cable with a Young's modulus (E) of 6.3 Mpsi 'A' is the cross sectional area of the particular cable chosen. The reduction site location 'x' and the transmission length 'L' are set equal to each other since speed reduction is done at the joint. The capstan size ratio (N) is the larger capstan diameter divided by the smaller diameter of capstan and the radius (R) of driven capstan is usually the radius of the larger capstan in the pair.

2.3.2 Loading Design Calculations

The calculations discussed in this section include the calculations for one pair of capstans and are taken from the final iteration of the shoulder transmission design for the cobot. The calculations for the shoulder, elbow and forearm rotation joints can be found in appendix B.

In section 2.2.2 the maximum user joint torque was found to be 1.58 N-m at 0.609 m. The target arm weight was 1.46 N-m at 0.32m creating the design target torque of 18.49 N-m. The total maximum torque T including design target torque and user torque at the shoulder joint is just under 56.45 N-m. A 100:1 reduction is necessary to accommodate the CVT input torque of 0.56N-m.

The shoulder capstan diameter was chosen to be 0.158m and the complimenting smaller capstan would have a diameter of 0.079m. In equation 2.1 the ratio of capstan size 'N' is given by the larger capstan diameter divided by the smaller capstan diameter.

$$N = \frac{0.158\text{m}}{0.079\text{m}} = 2 \quad (2.2)$$

Now a shoulder capstan size had been chose. The Shoulder torque 'T' is divided by the shoulder capstan radius; to determine the cable line loading 'CL'.

$$CL = \frac{56.45 \text{ N-m}}{0.079 \text{ m}} = 114.5\text{N} \quad (2.3)$$

The cable chosen must have a breaking strength of 10 times the working load, therefore a cable of 7116.8N breaking strength or more should suffice.

2.4 Cable Wrapping Design

Cable wrapping design requires that a cable spool consistently onto its capstan to offer better performance. Design of cable wrapping includes cable spacing to prevent scrubbing, supporting the cable on 1/3 of its circumference and consistency in axial cable travel. These three criteria can be fulfilled through the use of a helical groove for the cable to spool into.

The equation for matching axial cable travel through the respective capstan helixes is given below. The ratio of the large capstan radius ($D1$) to the small capstan radius ($D2$) multiplied by the small capstan helix height per turn ($H2$) should equal the larger capstan helix height per turn ($H1$).

$$\frac{D_1}{D_2} H_2 = H_1 \quad (2.4)$$

Please note that the limiting factor in this design is the helix on the smaller capstan as it has more wrappings than the larger capstan. Therefore it is advantageous to design capstan thickness starting from the smaller capstan.

2.5 Cable Tensioning Design

Cable transmission design depends on pre-tensioning the transmission cables to increase stiffness and eliminate backlash [11]. A pre-tensioning method that is simple, compact and non-destructive to the capstan shafts is desirable. A common method for smaller operational torques is to sandwich the capstans between a retaining ring and nut creating friction between the sandwiched capstans to maintain cable tension. The pre-tensioning of the sandwich capstan design may require 2 people to achieve. The wearable cobot designed to accommodate torques of up to 56.45N-m at the shoulder joint and while the static calculations confirm that the sandwiched capstan design would assist this torque. The creep in between the 2 capstans is difficult to determine.

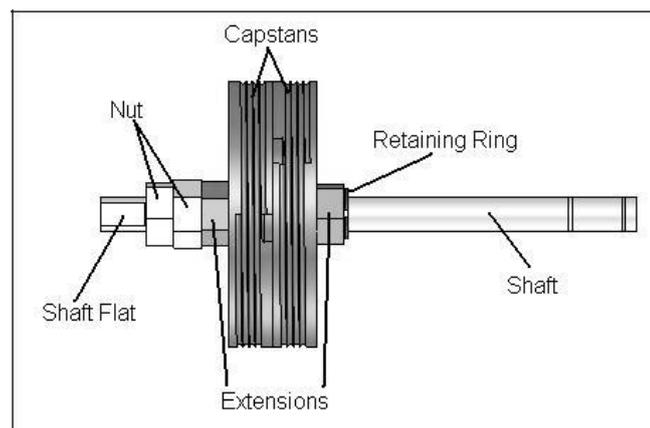


Fig. 5 Sandwiched Capstan Tensioning Scheme

In the wearable cobot the cable tensioning design consists of 2 cables, one for positive and negative torques each. Cable is rigidly connected to the capstans with all necessary fittings. Below is a diagram of the tensioning scheme in fig.5. In the wrist transmission, the sandwiched capstan tensioning method is used because of the relatively small capstan sizes and forces.

III. RESULTS

The starting torque for the shoulder transmission was found to be approximately 1.86N-m. The linear deflection of the arm under maximum loading is 0.014m. Empirical testing shows 0.0127 m of this deflection can be attributed to the bending of the arm. Therefore the linearized deflection due to cable compliance at 0.609m from the shoulder joint is 0.0019m.

Shaft A3 suffers from a noticeable amount of deflection when under full loading. Shaft A3 and shaft A4 bow towards each other due to the loading. Due to inconsistent transmission length this bowing creates a variable cable tension. The groove width of cable on the large capstan on shaft A3 was machined narrower by 0.000224m. This also creates a variable cable tension due to inconsistent axial cable travel between shafts A3 and A4. The bearing in shaft A4 contains a

foreign object, most likely a small aluminum chip that produces a rhythmic noise while in use and is likely adversely affecting performance.

CONCLUSIONS

3-DOF CVT robots were designed for use as a master controller in the operations of telerobotic. A detailed design of the robot arm is complete at this time. Its wearable design allows for an increased telepresence in terms of a 1-to-1 correlation in the movement of human arm. The robot cable driven transmissions allow joint torques to be suitably reduced for use with CVTs. This design is also the first to incorporate a wearable mechanism with spherical CVTs.

The shoulder transmission has been built, assembled and tested. Difficulties in assembly mainly dealt with convenience of disassembly to ease the wrapping of cable. An alternate mounting method between the capstans and shafts would help to better accommodate. Further research is warranted to determine an appropriate start torque for this system. Since the start torque is 1.86N-m the application of 3.06N (at 0.609m from the shoulder) to start movement will noticeably affect the sensitivity of the cobot. For bearings and cables the robot had been assembled for 2 weeks and a break in period of a few thousand cycles should be considered. Deflection occurs due to cable operation at 0.609m from the shoulder joint is 0.00198m. This transfers to a mechanical rotational stiffness of 17.85×10^3 , approximately 1/3 more stiff than theorized.

REFERENCES

- [1] Peshkin, M. A., Colgate, J. E., Wannasuphprasit, W., Moore, C. A., Gillespie, B. and Akella, P., Cobot Architecture, IEEE Trans.Robot. Automat. vol. 17, pp. 377–390, Aug. 2001.
- [2] Wannasuphprasit, W., Akella, P., Peshkin, M.A., Colgate, and J.E. “Cobot: a novel material handling Technology,” ASME Vol. 98-WA/MH-2, 1998.
- [3] Moore, Carl A. “Design, Construction, and Control of a 3-Revolute Arm Cobot,” Ph.D. dissertation, Dept. Mech. Eng., Northwest Univ., IL, 1999.
- [4] Schloerb, David W. A Quantitative Measure of Telepresence. Presence: Teleoperators and Virtual Environments. Vol. 4, no. 1, pp. 64-80. Winter 1995.
- [5] Rosenberg, Louis B. Virtual Fixtures: Perceptual Tools for Telerobotics Manipulation. IEEE Conference Proceedings, 1993, pp. 76-82.
- [6] Colgate, J. E. and Brown, J. M., 1994, “Factors Affecting the Z-Width of a Haptic Display,” Proc. IEEE International Conf. On Robotics and Automation, pp. 3205-3210.
- [7] Colgate, J. E. and Schenkel, G. C., 1997. “Passivity of a Class of Sampled-Data Systems: Application to Haptic Interface,” Journal of Robotic Systems, 14(1), pp. 37-47.
- [8] Faulring, E. L., Colgate, J. E. and Peshkin, M. A. A High Performance 6-DOF Haptic Cobot. Proc. IEEE ICRA, pp. 1980-1985, 2004.
- [9] Heckendorn, F. and Kress, R., “Outline for Large-Scale System Operations and D&D Report,” U.S Dept.of Energy, WSRC-TR-2000-00364.
- [10] Peters, R. A., Campbell, C., Bluethmann, W. J. and Huber, E. Robonaut Task Learning through Teleportation. Proc. IEEE ICRA, pp. 2806-2811, 2003
- [11] Salisbury, K., Townsend, W., Eberman, B. and DiPietro, D. Preliminary design of a whole-arm Manipulation system (WAMS). Robotics and Automation, 1988. Proceedings 1988 IEEE International Conference, April 1988 Page(s):254 - 260 vol.1
- [12] Townsend, William T., “The Effect of Transmission Design on the Force-Controlled Manipulator Performance,” Ph.D. dissertation, Artificial Intelligence Laboratory, M.I.T., MA, 1988.

