Identification and Control of Counter-traction Mechanism to Finger Traps for Fracture Reduction

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Abstract. Finger traps are a valuable tool that can be maintained the traction. The devices stretch the thumb and other four fingers separately in order to achieve better reduction effect. These are applied individually to the fingers and the limb is suspended, with gravity providing counter-traction to disimpact the fracture by traction. However, personal gravity can’t be used to maintain the appropriate tension. This paper proposed an experimental study on the tension of counter-traction mechanism to finger traps for fracture reduction. This mechanism is particularly useful to help for the patients. Transfer function estimation from experimental data can improve the overall identification performance and the parameter. The feedback control system design for compensating tension that loses from disturbance tension consisted of the controller as PI controller and actuator as DC motor with counter-traction mechanism. Experimental results were demonstrated the efficiency of the proposed system to maintain the appropriate tension.

1. Introduction

Recent decades, surgical approaches such as open reduction and internal fixation have been increasing use. Complications such as tendon afflictions and further surgery can arise from surgical intervention. Therefore, closed reduction and cast immobilization remains an important treatment option in a majority of cases. A very commonly used method of closed reduction is manual traction. An assistant provides counter-traction while the operator provides traction and manipulates the bone fragments into position. Even though it has been the most commonly used method for at least the better part of a century, the evidence of its effectiveness is ambiguous [1]. Another method is mechanical reduction by finger-trap traction [2] which dispenses with the need for an assistant as the forearm is suspended by finger-traps in the radial fingers. The traction mechanism stretches the thumb and other four fingers separately in order to achieve better reduction effect [3]. Counter-traction is provided by weights suspended on the arm near the elbow joint with gravity as shown in Figure 1. This restores the longitudinal axis without further actions, and the operator can then apply manual dorsal pressure to the fragments, if necessary, to restore the volar tilt of the wrist [4]. Closed reduction by finger-trap traction seems to offer better correction of radial shortening. However, the optimal weight to relate with tension of closed reduction remains to be determined.
This paper proposed an experimental study on the tension of counter-traction mechanism to finger traps for fracture reduction. This mechanism is particularly useful if there is no assistant available. Simplistic transfer function, to improve the overall identification performance, the parameters and mechanism were first estimated using a DC motor signal. The PI controller with the DC motor control has been design based on the concept of feedback control system for compensating tension load that loses from disturbance tension.

2. System modelling

The objective is to model the interaction between the counter-traction mechanisms with tensions of DC motor control. Although the counter-traction mechanism that controls the positions and torques of mechanism in follow the tensions generated by controller. In general, the drive system contains two major parts. The first one is the electronic control system, actuator, controller, and load cell. The second one is the mechanical system such as the motor, lead screw, spring, and tension connector, etc. The control system with feedback is a closed-loop system as shown in Figure 2.

![Figure 1. Finger-trap traction](image1)

![Figure 2. The diagram of counter-traction mechanism](image2)

2.1. Counter-traction mechanism

The motor models have been proposed for system identification and controller design [5]. The motor torque is transmitted to the lead screw with tension connector that has a damping coefficient of rotary motion \(B\) and angular displacement \(\theta\).
where $J$ is the total inertia of coupling, motor shaft, tension connector and lead screw.

The torque, which is used to move the tension connector, is generated by applying input voltage ($V$) to the amplifier which has a torque constant ($K_t$), such as

$$V = L \frac{di}{dt} + iR + K_e \frac{d\theta}{dt}$$

$$T = K_t i$$

The current ($i$) is fed to control the DC motor, where $L$, $R$ and $K_e$ are inductance, resistance, and back electromotive force constant of DC motor, respectively. The tension load ($F$) from wire tension at nut of lead screw is transmitted as the axial load torque ($T_L$) as

$$T_L = F \otimes r$$

Where $\otimes$ denote the cross product operation is perpendicular. The total axial displacement of the tension connector is contributed by the axial movement of the lead screw reflected at the nut ($X_s$) and the angular displacement ($\theta$) of the lead screw translated as the axial displacement [6].

$$F = K_s X_s = K_s r \theta$$

where $K_s$ is tension gain of spring, and the transmission ratio is $r = p/2\pi$ with pitch length ($p$).

Taking Laplace transform of equations (1) through (5), the transfer function between the tension load ($F$) and input voltage ($V$) can be expressed as

$$F(s) = \frac{r K_s K_t}{J L s^3 + (BL +JR)s^2 + (r^2 L K_s + BR + K_e K_t)s + r^2 R K_s}$$

The mathematical model in equation (6) is the theoretical analysis of dynamic phenomena of the counter-traction mechanism. The parameters of the model aren’t an unknown and uncertain values.

2.2. System identification

Methods of system identification, parameter estimation and optimization applied to problems of modelling and control. The counter-traction mechanism is the closed-loop control process [5]. The mathematical model can be estimated from experimental data. In this, the most popular method for curve-fitting is described. Collection data base on time domain, the desired tension was constant at 3 N, an initial condition. The input signal was generated the desired reference a force between 50 to 80 N and each of the step was changed 10 N with 400 seconds.

**Figure 3.** The performance of identification and measurement

**Figure 4.** Comparative convergence of the response at 80 N
Thus, the approximated parameters from identifications as shown in table 1, and rearrangement are given by

$$\frac{F}{V} = \frac{b_0}{s^3 + a_2 s^2 + a_1 s + a_0}$$

(7)

| Symbols                                      | Values    |
|----------------------------------------------|-----------|
| $b_0 = rK_tK_s/JL$                          | 2.6       |
| $a_0 = (BL+JR)/JL$                          | 4.4e-3    |
| $a_1 = (r^2LK_s+BR+K_tK_e)/JL$              | 9.6e-1    |
| $a_2 = r^2RK_e/JL$                          | 9.7e-1    |

The responses that behaviors of the system identification to simulate (solid line), measurement (gray line), and desired tension (dashed line) were shown in figures 3 and 4. In the extended scale in a point of tension at 80 N, the behavior transients of the convergence comparisons can be expressed the response as shown in figure 4. The phenomenal response reveals the rise time of 8 seconds, the settling time of 9 seconds (steady state of 2%) and the overshoot of 1.5%.

### 3. Experimental and simulation results

In this section, to test effectiveness of the proposed control method, simulations and experiments were carried out on the counter-traction mechanism on tensions of DC motor for position control with PI controller as shown in figure 5. To realize the proposed digital control system using a digital signal processor (DSP), the DSP-board manufactured by Maneesoon Group Company Limited (MNS) was utilized. Control algorithms were programmed in the MATLAB and Simulink environment and were then compiled and loaded to the DSP-board. The sampling frequency was 1 kHz. At each sample time, four successive 12-bit A/D conversions of each signal were taken. Moreover, there were interface circuits for command and data communication between the computer and the development module. In addition, the corresponding tension load was measured via load cell sensor. The input range of each channel was from 0 to 5 volts.

**Figure 5.** The counter-traction mechanism, (1) tension connector, (2) lead screw, (3) DC motor, (4) spring, and (5) load cell sensor
3.1. Performance of desired input tracking
In the response optimization of PI controller, the maximum overshoots by 2% in the step response. The rise time and settling time are less than 15 (80%) and 20 (2%) seconds. The controller parameters are optimized to be $P = 0.1219$ and $I = 7.8097e^{-4}$.
For comparison purpose, a display the response impulsive reference using input tracking based on optimal controller, shown in figures 6 and 7. These results strongly suggest the optimal controller that were capable reducible the effect of the overshoot and steady-state error.

![Figure 6](image1.png)  ![Figure 7](image2.png)

**Figure 6.** The tracking performance of optimal PI controller  
**Figure 7.** Comparative convergence of the response at 80 N with optimal PI controller

3.2. Robust disturbance
In the final test, the experimental result with a disturbance response was studied with the response effect to the dynamics of the system when there is a change of the external force interference. Applying traction to fracture reduction requires constant tension. For disturbance testing, changing the position of tension connector upward or downward one step will change the tension increase or decrease with magnitude of 8 N. There are two types of controller's working conditions.

![Figure 8](image3.png)  ![Figure 9](image4.png)

**Figure 8.** The responding of immediate self-adjustment  
**Figure 9.** The transient response of immediate self-adjustment at 80 N

3.2.1 Immediate self-adjustment. The disturbance of response is a function with a peak amplitude from the set point. This is considered the robust external interference that occurred. When the system was disturbed, the output tension changed from desired tension that controller could be adjusted tension by itself. Figures 8 and 9 show the response of the optimal PI controller with the disturbance. At steady state 80 N, the system was disturbed by increasing 8 N at time of 1300 sec. The maximum tension is 88 N. After that the system can be recovered to steady state with the settling time of 10
seconds (2%). The controllers are suddenly robust to external disturbance, but the response occurred the overshoot more than 10%.

3.2.2 Conditional self-adjustment. The actual application, the disturbances from the tension can be predicted the boundary. So, the system was disturbed with 8 N, then an increase or decrease disturbance occurred the boundary at ±5% of the references. The controllers are suddenly robust to external disturbance over ±5% of the references and aren't adjusted the tension under boundary as shown in figures 10 and 11, respectively. The controllers are suddenly robust to external disturbance in the boundary conditions.

![Figure 10. The responding of conditional self-adjustment](image1)

![Figure 11. The transient response of conditional self-adjustment](image2)

4. Conclusions

The analytical and experimental results of counter-traction mechanism demonstrate the effectiveness of identification and control of wire tension in a closed loop system. In the beginning, prescribed the PI controller for the system are applied to maintain position with relative the tension load. Transfer function of estimation explained, the phenomenon between tension and controller was designed by using an optimal PI controller. The results of a comparative study between an immediate and conditional self-adjustment for the counter-traction mechanism were discussed in terms of transient responses and steady state responses. The feedback system can be maintained the tension with compensation that loses from disturbance in specific range of 50-80 N.

5. References

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