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Design of a Portable Dynamic Calibration Instrument for daVinci Si Tools

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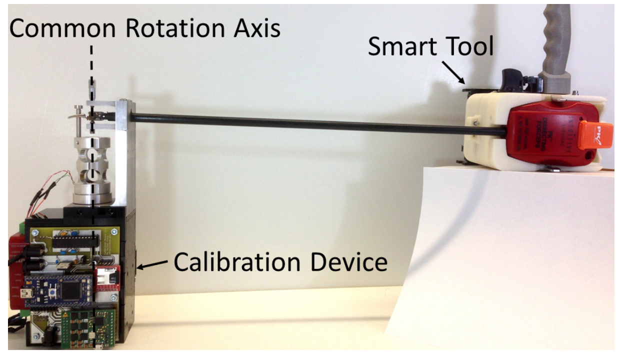

FIGURE 1: Overall Set-up

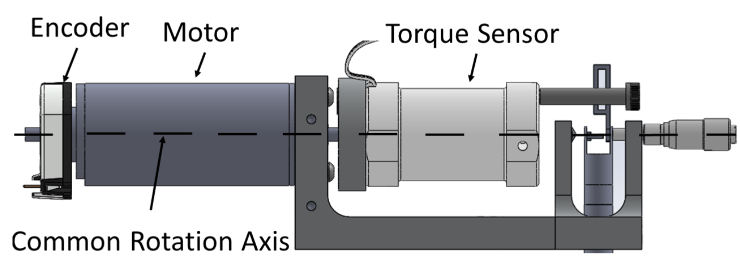

FIGURE 2: CAD Design

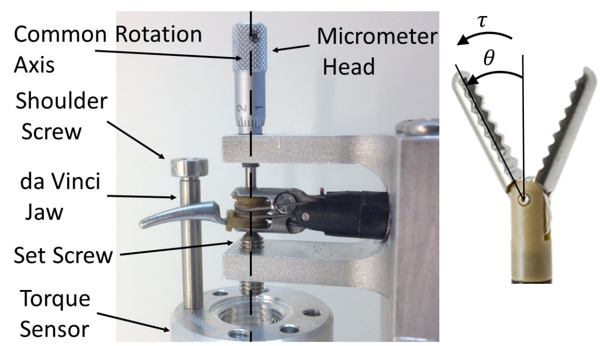

FIGURE 3: da Vinci Si Maryland Graspers Being Tested

1 Background

Tissue crush injuries are more prevalent with laparoscopic surgery than open [1]. Injuries may become more frequent in robotic surgery, because force is often only evaluated by the visual deformation of the tissue [2]. A proposed solution by Sie et al. to mitigate these surgical errors is to create tissue-aware graspers which can be incorporated into existing surgical robots, such as the da Vinci [3]. Stephens et al. created a tissue-aware grasper using backend sensing on a da Vinci Si tool [4]. However, tissue identification can be further improved through properly understanding a dynamic da Vinci tool model. Therefore, instrumentation that can accurately and fully characterize existing robotic tools is needed. Various tool calibration set-ups have been created such as [5], which are not portable and often neglect dynamic ranges. The goal of this paper is to present a portable device that shows promise in capturing the dynamic range for da Vinci Si tools.

2 Methods

The overall set-up utilized back-end sensors from the previously described da Vinci tool driver detailed in [4] referred to here as the Smart Tool (Fig. 1) with a da Vinci Maryland Grasper (Intuitive Surgical, Sunnyvale, CA). The Smart Tool was used as a portable surrogate for the sensors available on the da Vinci platform with an additional sensor for torque, and controlled the frequency of each grasp. The calibration device consisted of a motor and optical encoder (Precision Motors, inc., Fall River, MA) mounted on an aluminum baseplate with an aluminum hub attached to the motor shaft shown in Fig. 2. The calibration device was used to provide a variable, constant torque for each test. A reaction torque sensor (Futek, Irvine, CA) with a precision ground shoulder screw was mounted onto the hub. The da Vinci jaw's axis of rotation was concentrically fixed to the motor shaft by grasping the jaw's pin on one side with a cone point setscrew and the other side with a ball-tipped micrometer head (Mitutoyo, Aurora, IL) as shown in Fig. 3. The absolute end effector angle was measured relative to the jaw pointing along the shaft's axis, as shown in the right side of Fig. 3.

An mbed microcontroller (NXP Semiconductors, Eindhoven, Netherlands) was used to send control signals and receive sensor data. A signal conditioner (Futek, Irvine, CA) amplified the analog signal from the torque sensor to an analog to digital converter (Texas Instruments, Dallas, TX). A motor controller (Maxon Precision Motors) utilized current feedback control to provide varying levels of reaction torque during testing. All data were sampled synchronously at 1 kHz.

A sine trajectory in position was implemented at the Smart Tool end to simulate a typical grasping scenario. Testing was done in pair-wise combinations of 0.1 Hz and 0.5 Hz input frequency, and 10 mNm and 35 mNm applied reaction torque at the end effector. The reaction torques were chosen to replicate a light grasp and a medium strength grasp, and the frequencies were chosen to replicate a quasi static grasp and a medium speed grasp, half the max speed of Smart Tool.Torque data were filtered using a 4^{th} order, low pass Butterworth filter with a cut off frequency of 60 Hz. Position data were filtered using the same filter for comparison reasons.

3 Results

The calibration device was assembled and integrated with the Smart Tool for data collection. The mass and dimensions of the final assembly were measured to be 958 grams and 8x6x22 centimeters, respectively. The resolution for the encoder was determined to be 0.09°, and the resolution for the torque sensor was determined to be 0.041 mNm. The Smart Tool position data were plotted against end effector position as measured by the calibration device shown in Fig. 4. These plots were done for each pairwise combination: 0.1 Hz and 10 mNm, 0.1 Hz and 35 mNm, 0.5 Hz and 10 mNm, and 0.5 Hz and 35 mNm. The Smart Tool torque data were plotted against end effector position for each pairwise combination as shown in Fig. 5. The lower two lines are at 10 mNm and the upper two lines are at 35 mNm.

4 Interpretation

The dynamics of the da Vinci tool is evident in Fig. 5 as there is vertical separation between the two frequency levels at 35 mNm. The thickness of the lines in Fig. 5 represents the variability in the data. The angle dependence of the da Vinci tool's cable-pully transmission is evident. In Fig. 4, Smart Tool spindle positions relate linearly to end effector angles for all permutations tested. Whereas, in Fig. 5 the grip force varies with yaw angle, which is consistent with findings by Lee et al [6]. In Fig. 4, non-negligible cable stretch is also evident given the offset of data segments for the two different applied torques.

The calibration device was light and compact enough to be used portably. Sensor resolution and accuracy were at an acceptable range for measuring dynamics of a da Vinci tool (Fig. 5) and shows promise in gathering the full dynamic range of surgical robotic graspers. This data can ultimately be used to create a dynamic tool model for tissue-aware graspers.

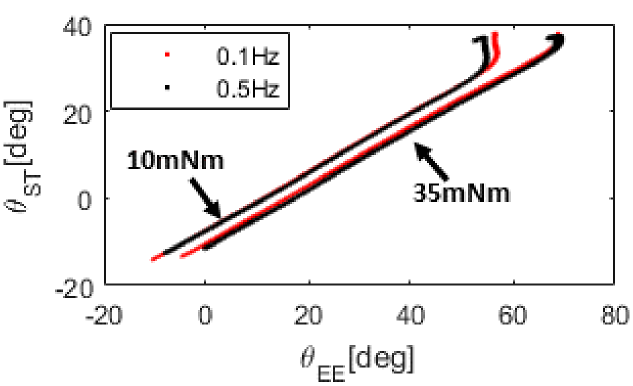

FIGURE 4: Smart Tool (ST) spindle position vs. end effector (EE, grasper) position for each pairwise combination

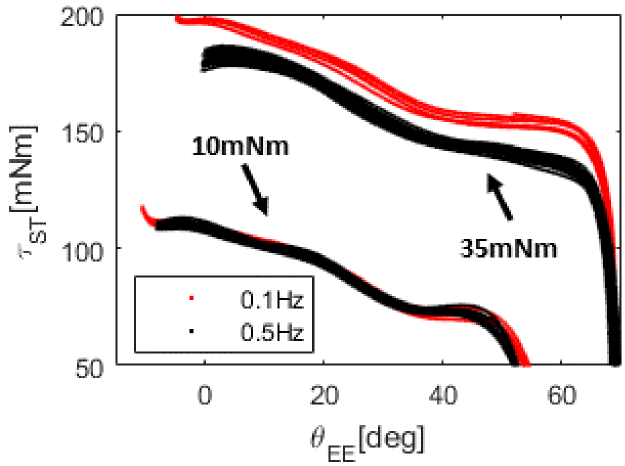

FIGURE 5: Smart Tool (ST) spindle torque vs. end effector (EE, grasper) position for each pairwise combination

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