A System for Torque and Speed Control of DC Motors with Application to Small Snake Robots

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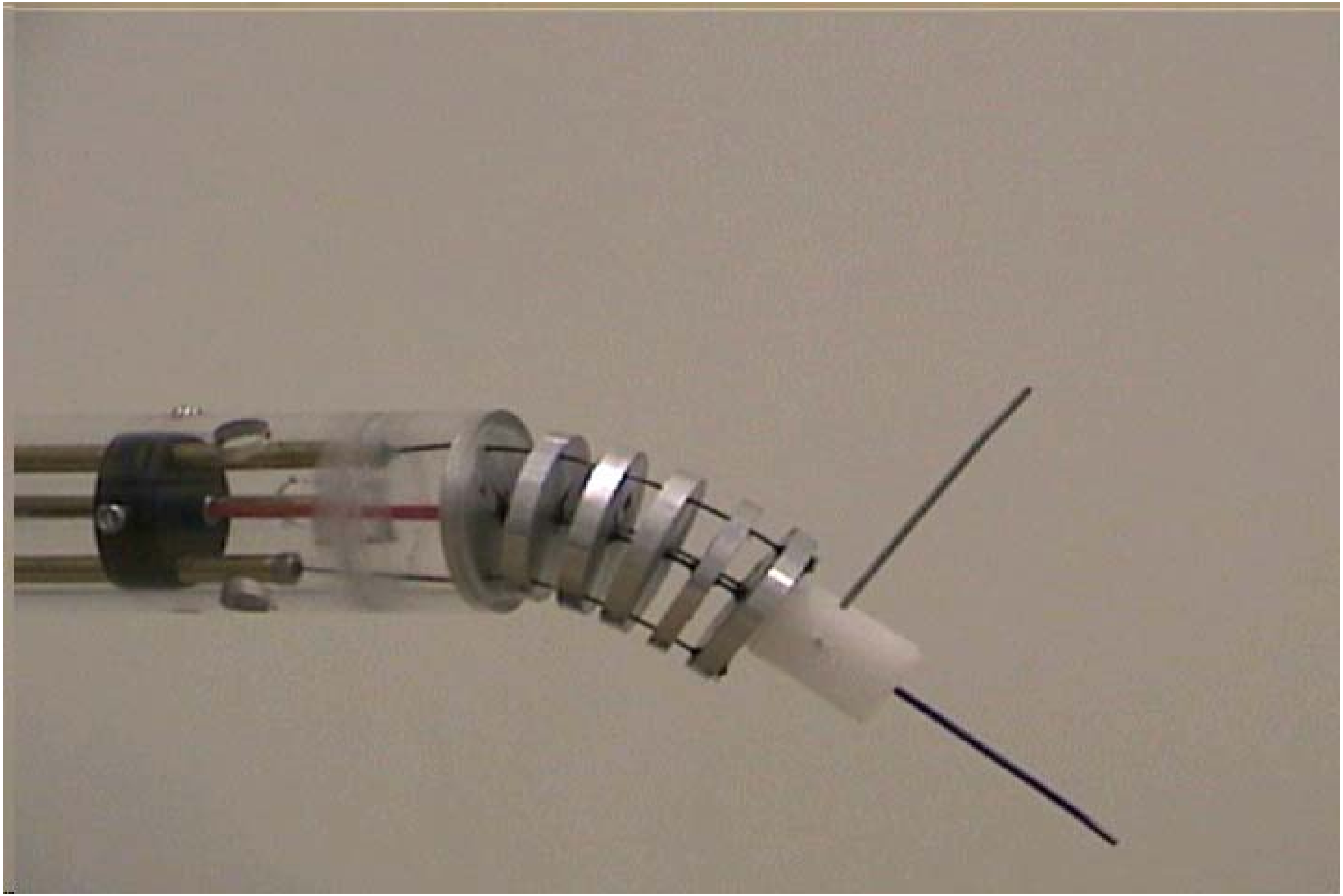
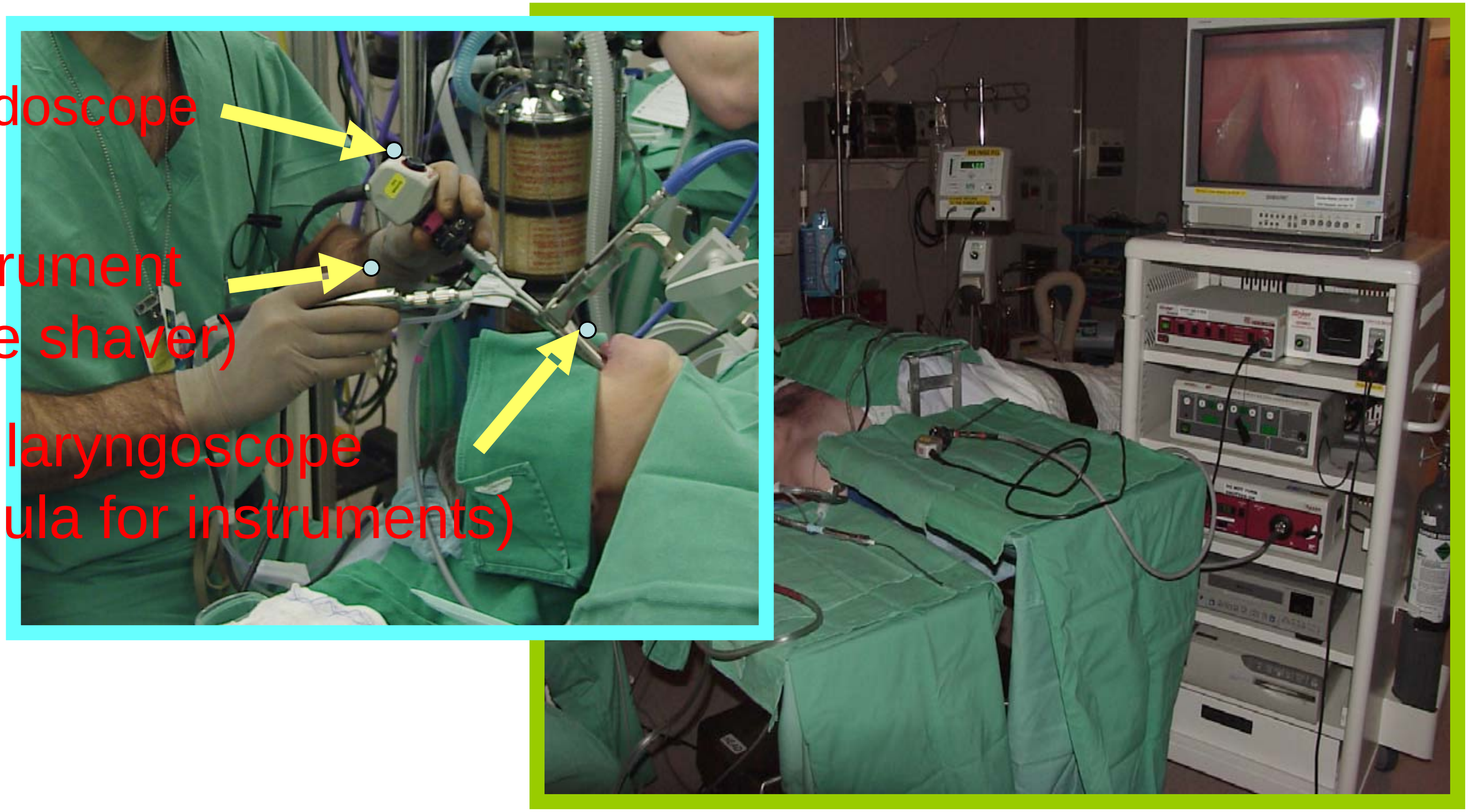


Overview of the Surgical Setup in Throat MIS*



*Courtesy of Paul Flint M.D. Johns Hopkins School of Medicine

Limitations of the Surgical Setup

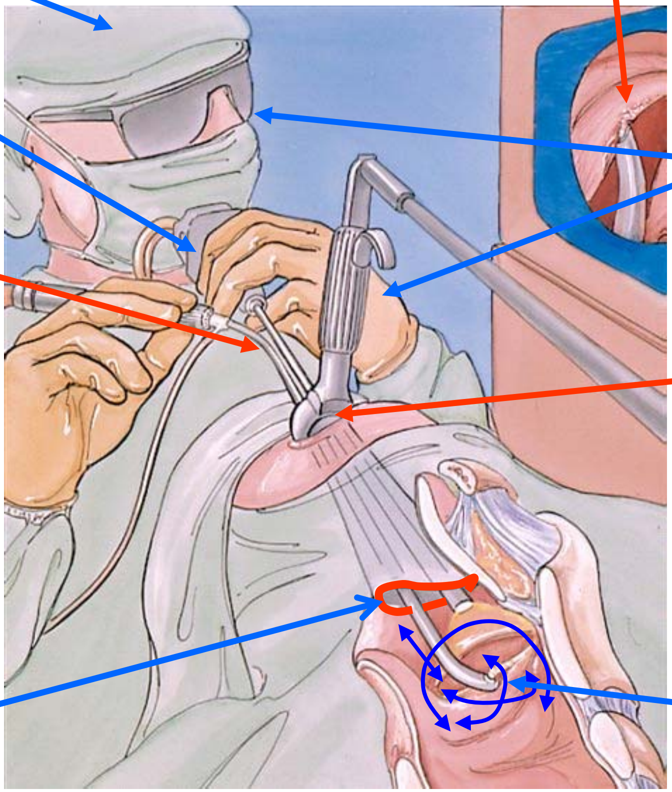
Haptic information deficiency

View limited by soft tissue

Multiple tools

Hand-eye coordination

Long rigid instruments



Predetermined entry port

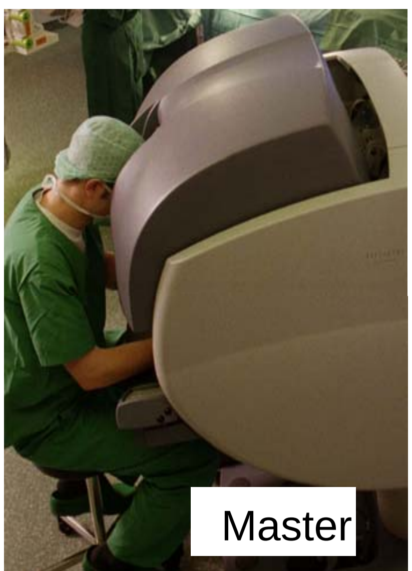
4 DoF motion constraint

No distal dexterity

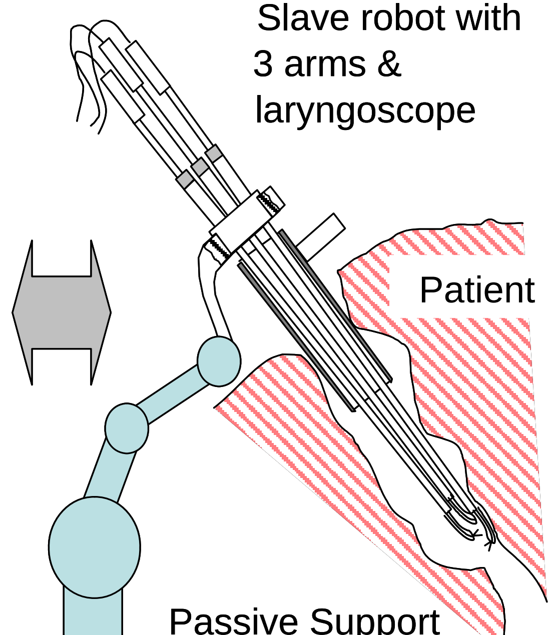
No suturing or functional tissue reconstruction capability

Teleoperated MIS of the Throat

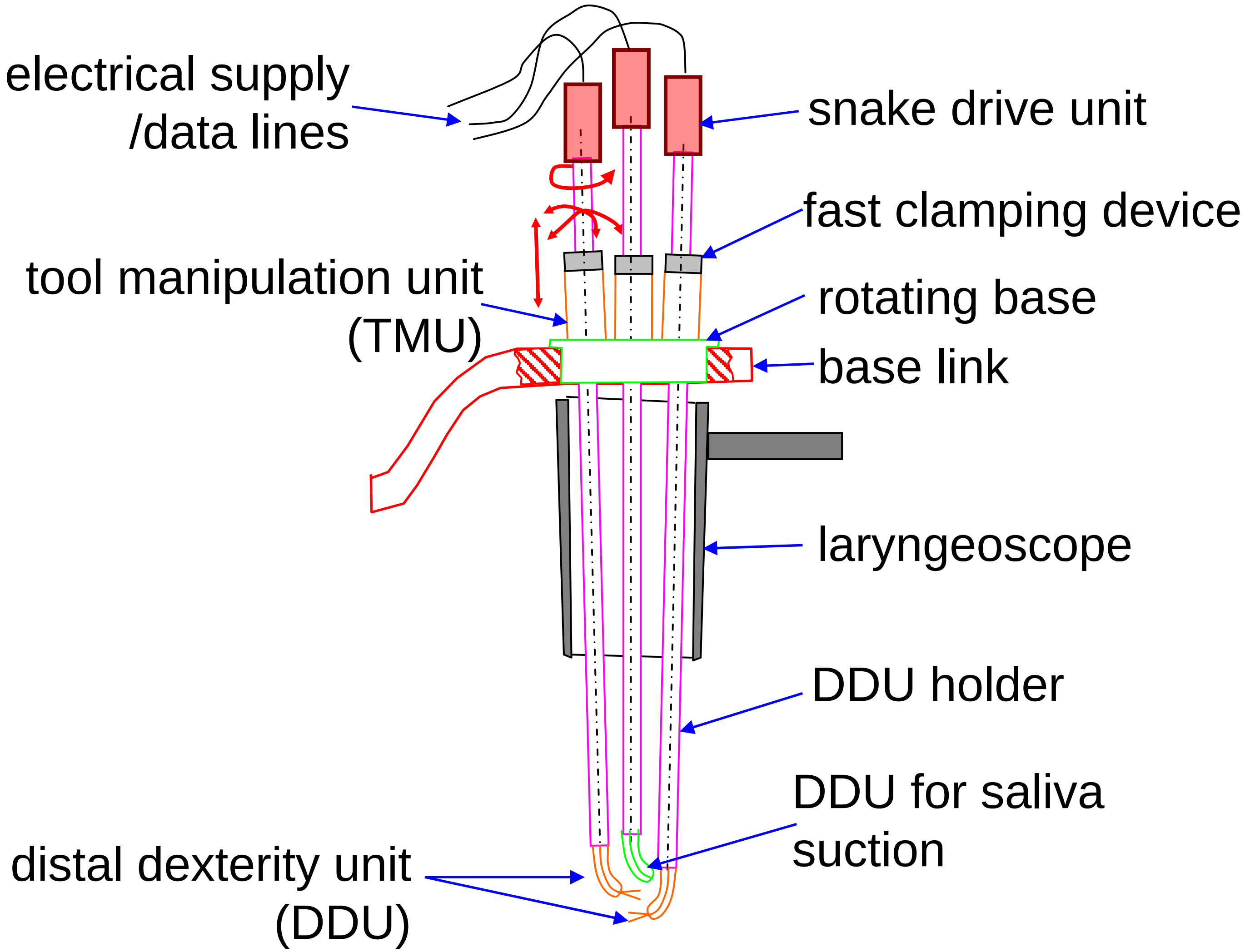
- This clinical problem motivated the development of three-armed tele-operated robot with high distal dexterity
- This paper presents the electrical hardware and test results for a single axis prototype



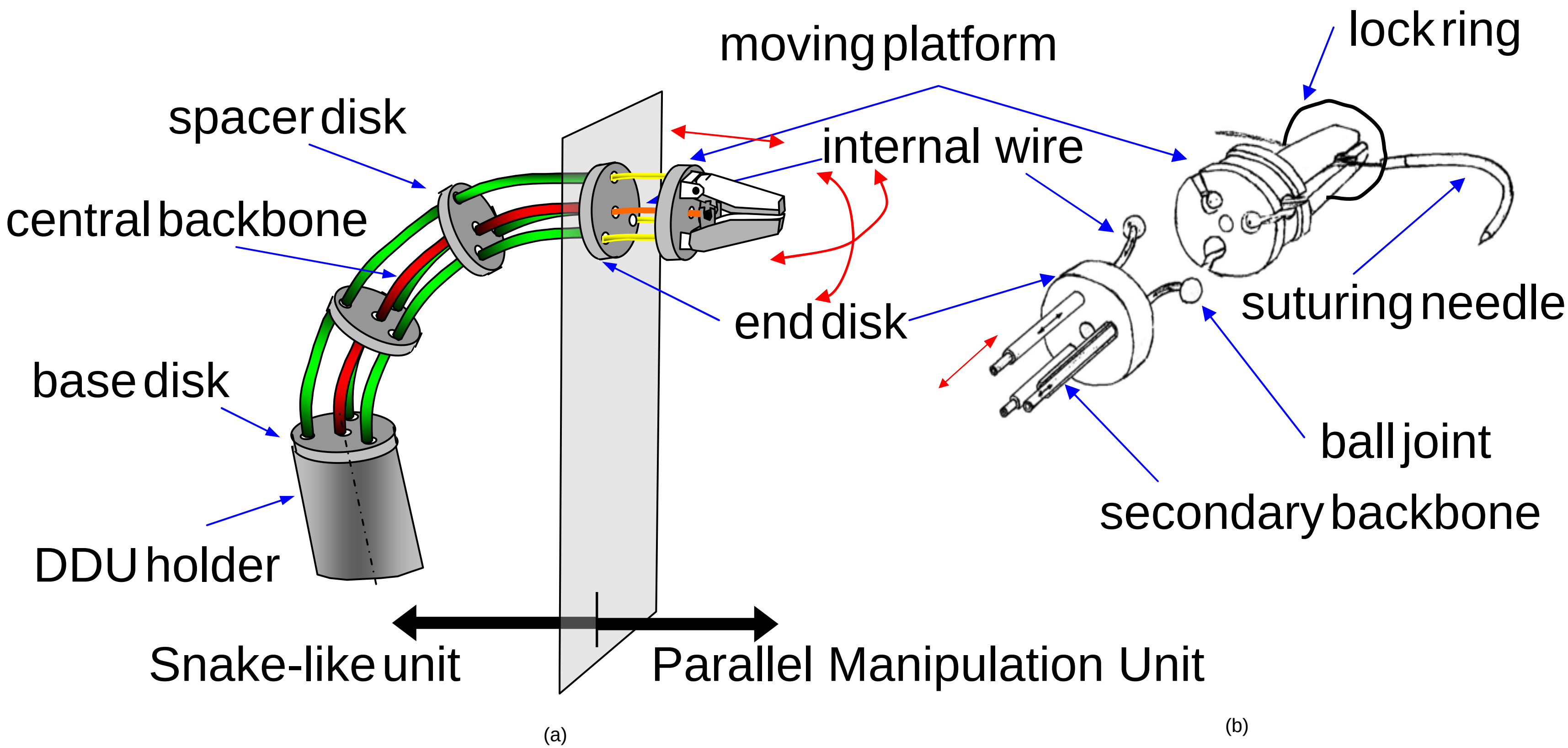
Controller
- Surgeon & master interface
- Slave control
- Registration to preoperative data
- “Virtual fixtures” & higher level task control



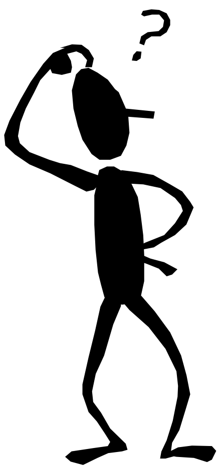
Slave Robot Design

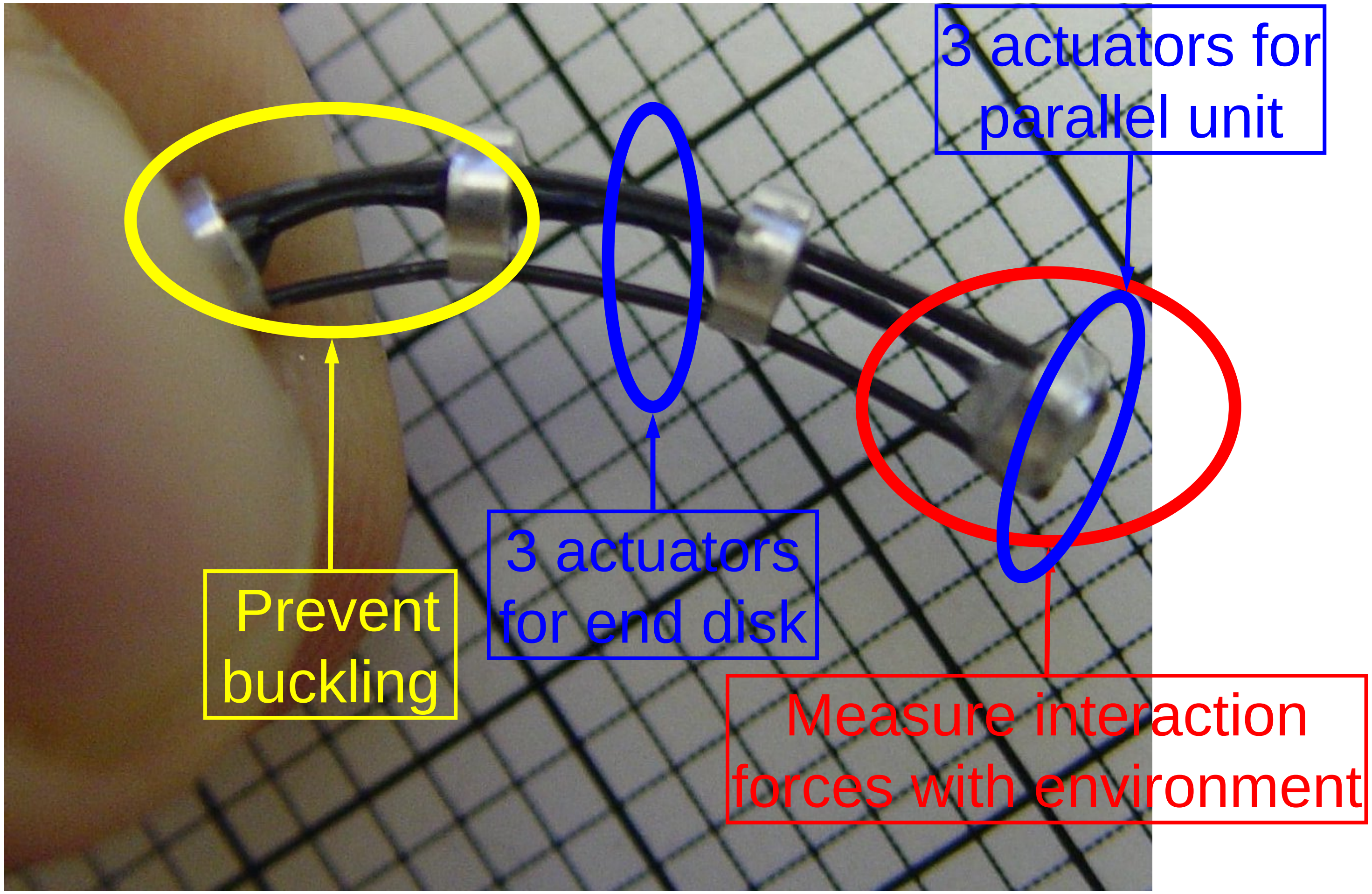


The Distal Dexterity Unit (DDU)



Requirements

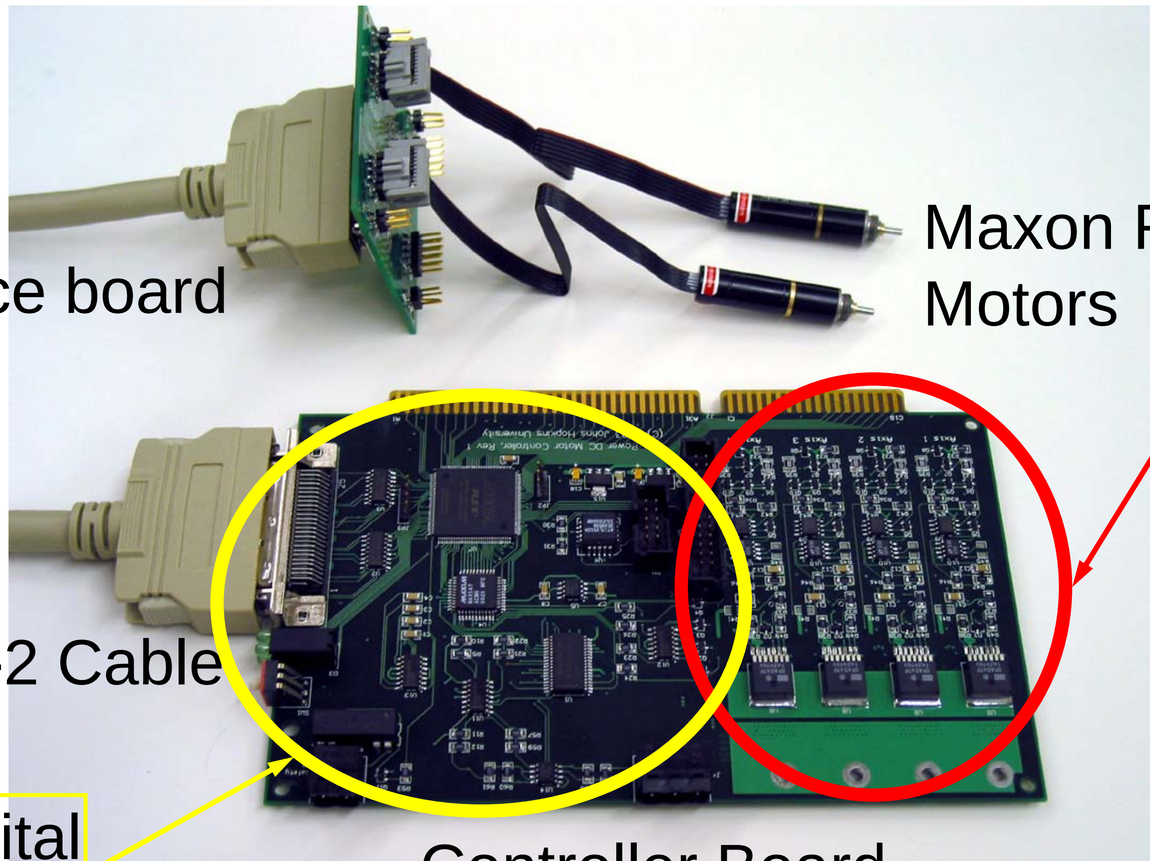




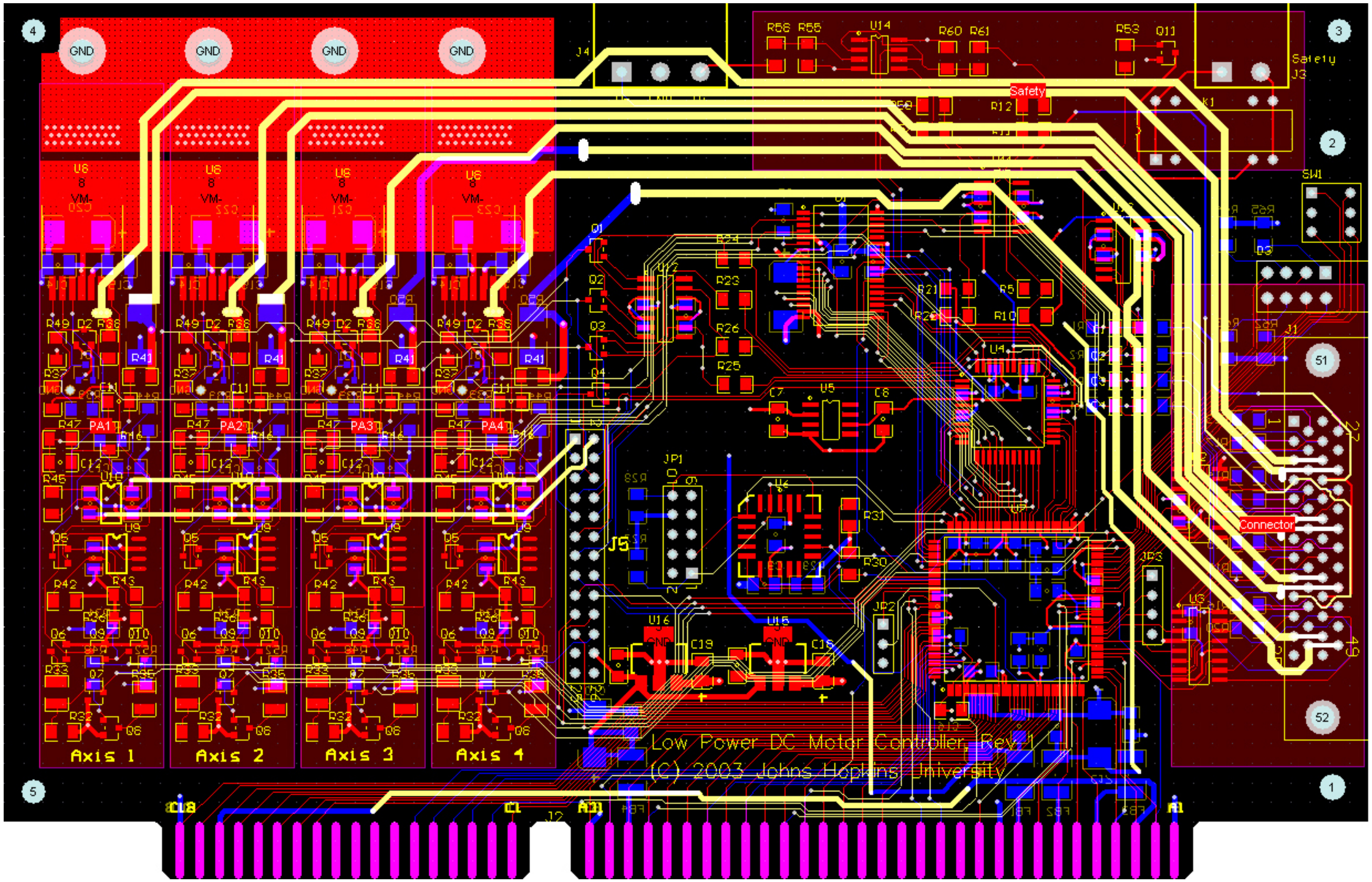
Requirements

- Control three 7-axis DDU's, three 4-axis TMU's and one RBU
- Prevent buckling by operating within strain limits of secondary backbones
- Initialize (HOME) with little or no motion
- Measure and limit interaction forces with enviroment

LoPoMoCo


Interface board
Maxon RE-10
Motors
Power
Section
SCSI-2 Cable
Digital
Section
Controller Board

PCB Layout

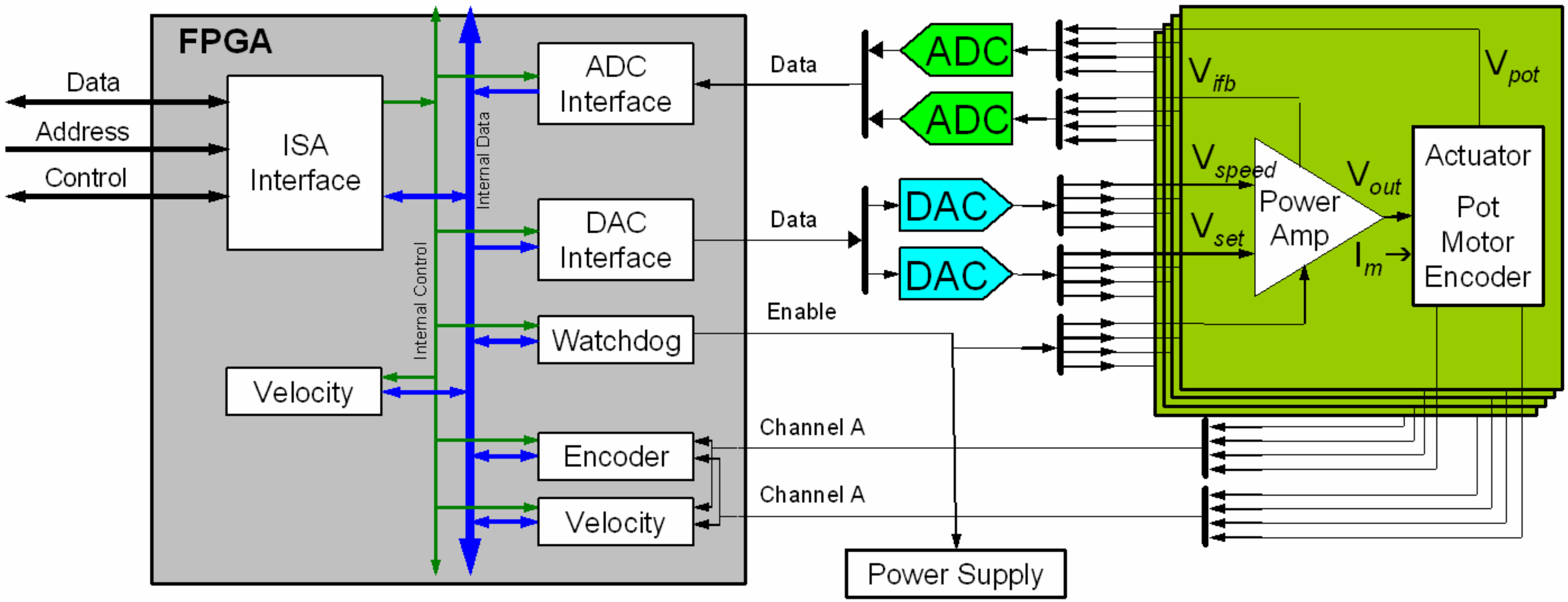


Axis 1
Axis 2
Axis 3
Axis 4
Low Power DC Motor Controller, Rev 1
(C) 2003 Johns Hopkins University
Safety
Connector

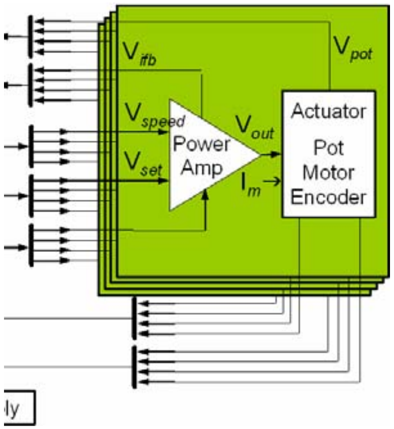
Electrical Design

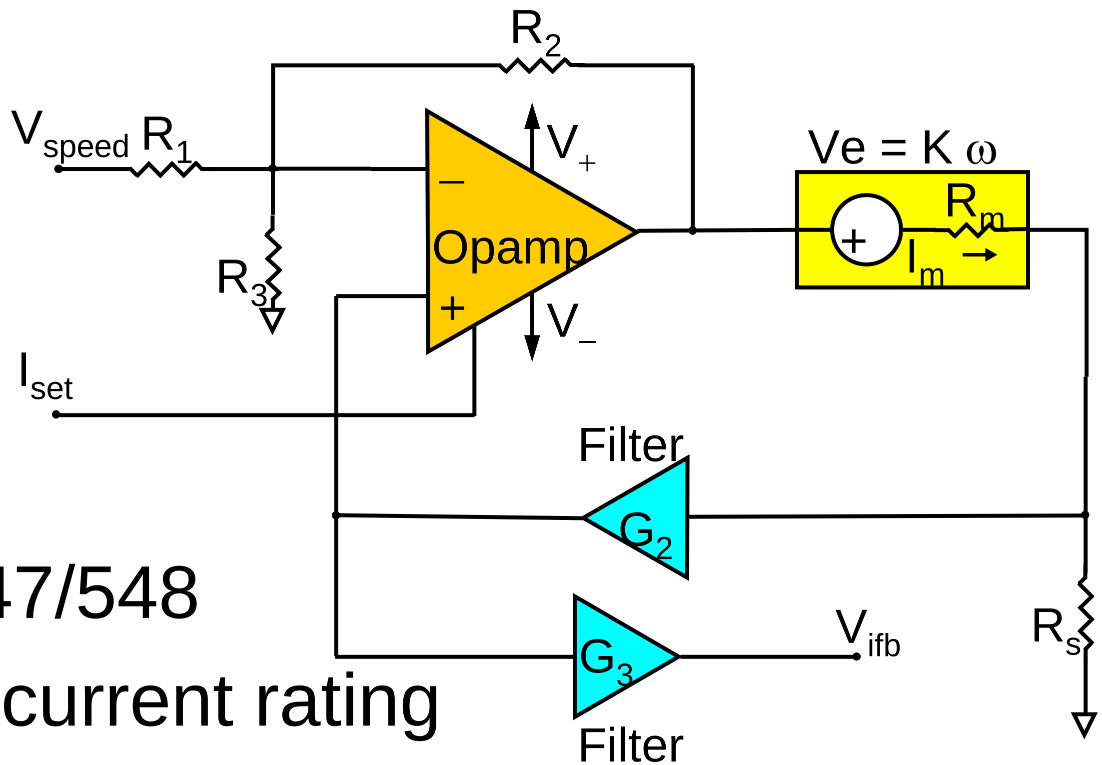
- Could not satisfy all requirements with commercial hardware.
- Designed custom hardware to:
  - Control motor speed AND torque
  - Accurately measure very low motor currents (less than 100 mA)
  - Simplify cabling to improve reliability
  - Obtain very low hardware cost

Block Diagram



Power Amp Section





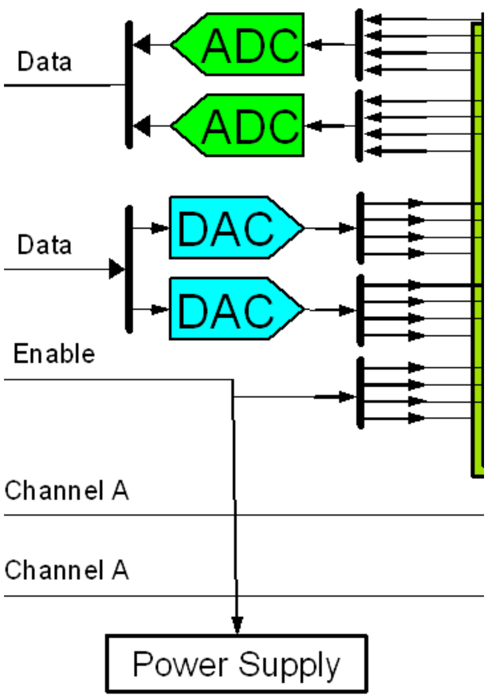
- Uses OPA547/548
- 500mA (3A) current rating
- 750mA (5A) max current
- Proportional speed control
- Control input to set maximum current

Speed Control

- Model motor by voltage source V_e (back-emf) and series resistance
- Want V_e to remain constant for constant input voltage V_{speed} regardless of motor load (motor current): $dV_e/dI_m = 0$
- Solve equation for values of G2 and R3

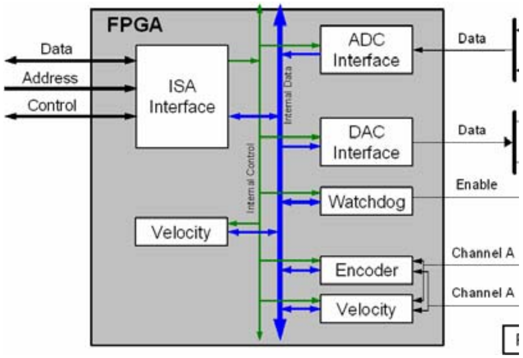
$$R_3 = \frac{R_2 G_2}{\frac{R_m}{R_s} - \frac{G_2 R_2}{R_1} - (G_2 - 1)} \qquad G_2 \le \frac{\frac{R_m}{R_s} + 1}{\frac{R_2}{R_1} + 1}$$

DAC/ADC Section



- Digital to Analog
  - Includes MAX547, 13-bit octal DAC
  - 4 voltage out for motor speed
  - 4 current out for current limit
- Analog to Digital
  - Includes MAX125, 14-bit 2x4 channel ADC
  - 4 motor current feedback
  - 4 analog potentiometer feedback

FPGA Section



- Uses Altera FLEX10K30E
- ISA Interface with PC
- Interface to DAC/ADC
- Position measurement from quadrature decoding
- Watchdog timer
  - Resolution: 122.93 μs
  - Total period: 125.88 ms
- An interval timer
  - Resolution: 30.73 μs
  - Total period: 31.48 ms
- Precise velocity measurement
  - Time between encoder transitions (1/DT)
  - Number of encoder transitions per time interval (DP/DS)

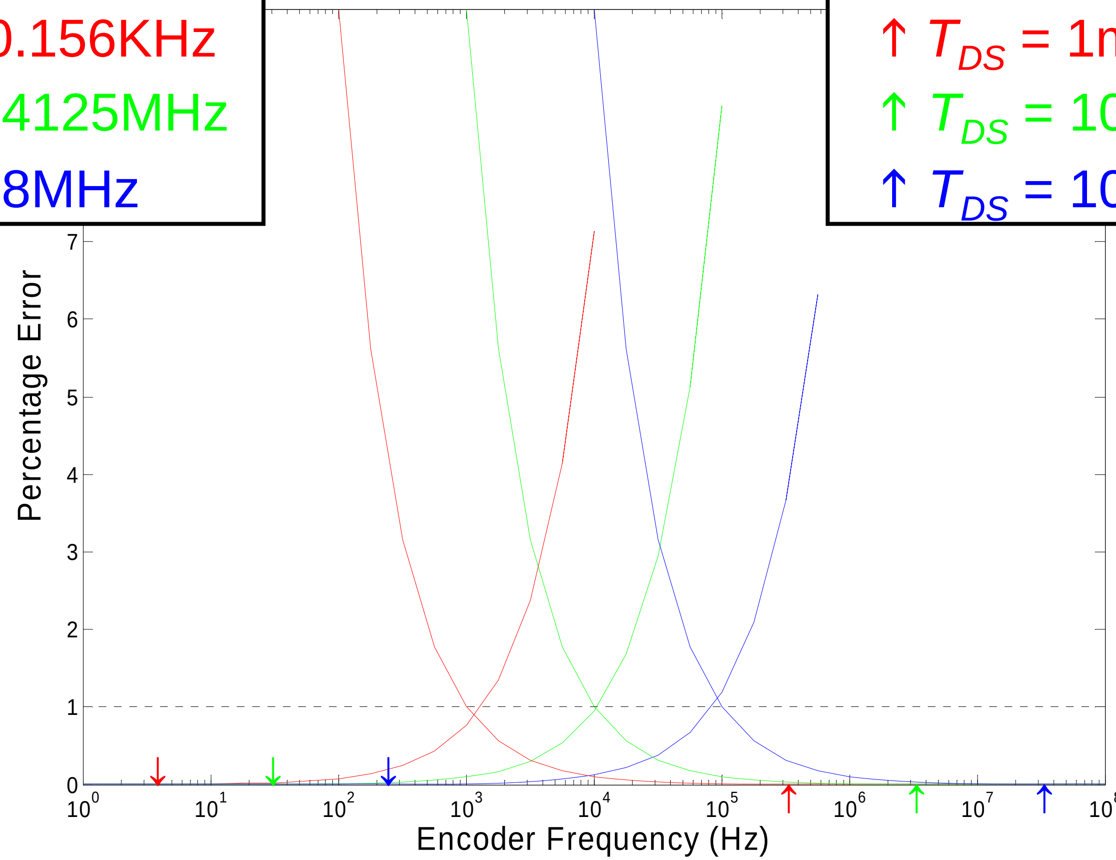
Velocity Measurement Design

16-bit overflow for 1/DT

- ↓ f_{DT} = 130.156KHz
- ↓ f_{DT} = 1.04125MHz
- ↓ f_{DT} = 8.38MHz

16-bit overflow for DP/DS

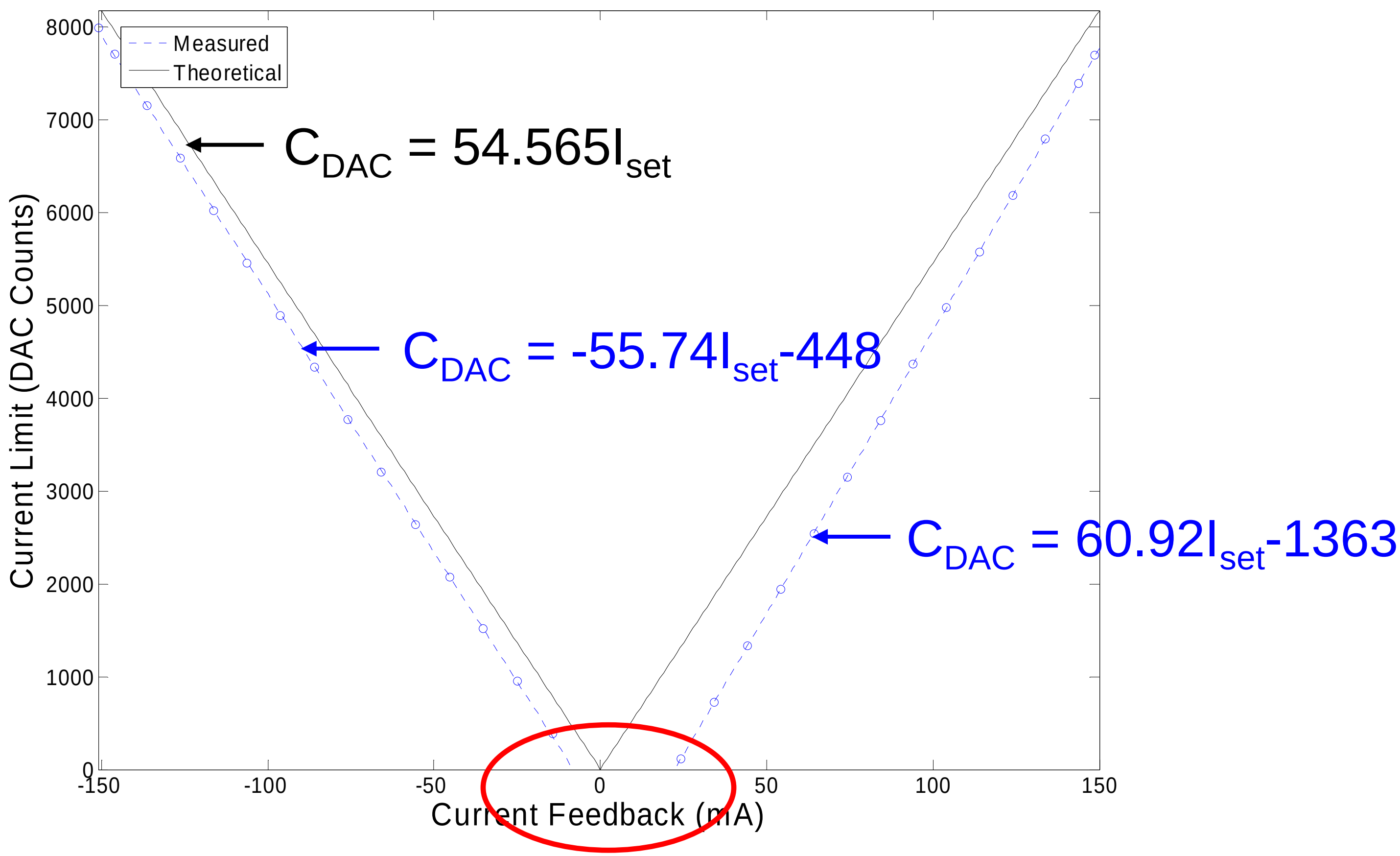
- ↑ T_{DS} = 1ms
- ↑ T_{DS} = 10ms
- ↑ T_{DS} = 100ms



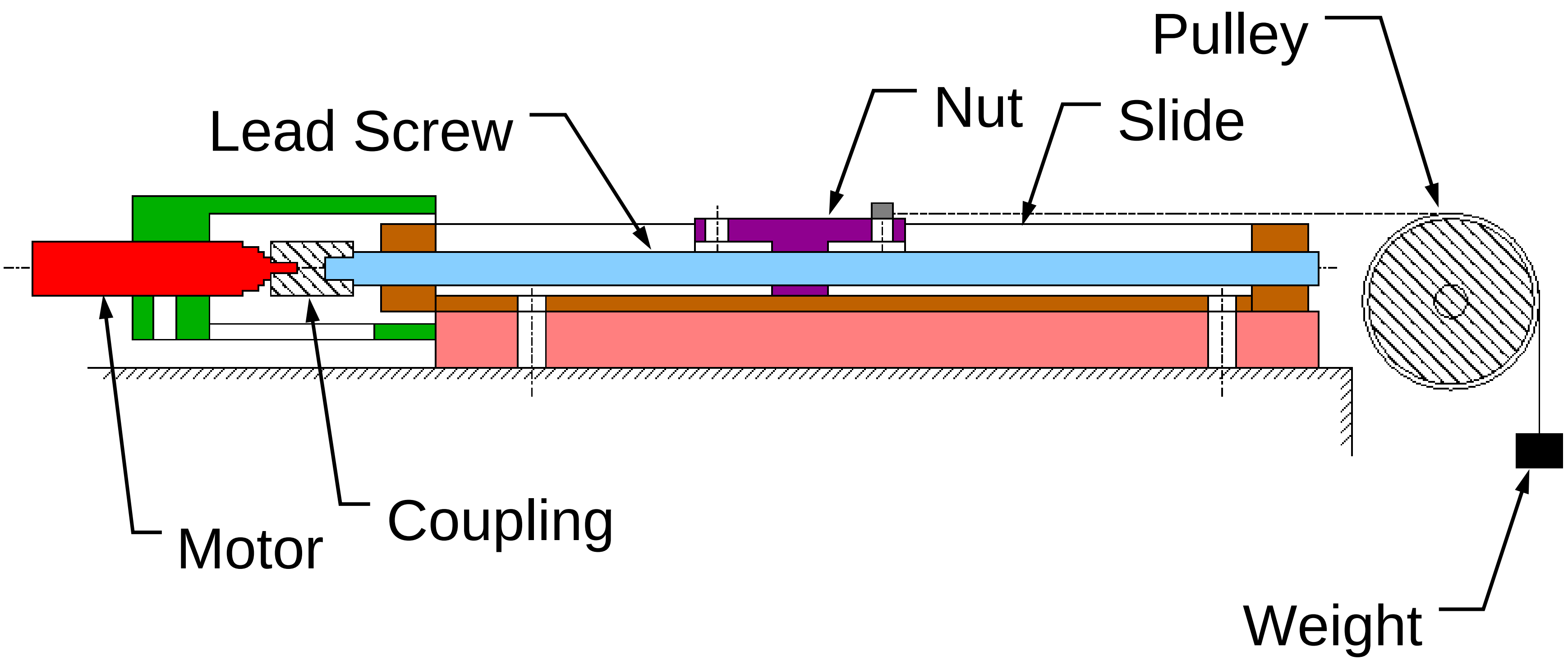
Test Results

- Built prototype actuation unit for one motor (of three motors to actuate snake)
- Tested ability to sense applied load using motor current feedback:
  - Attached known weights and moved motor at different speeds
- Tested ability to control motor current:
  - Attached known weight and slowly decreased current limit until motor stalled

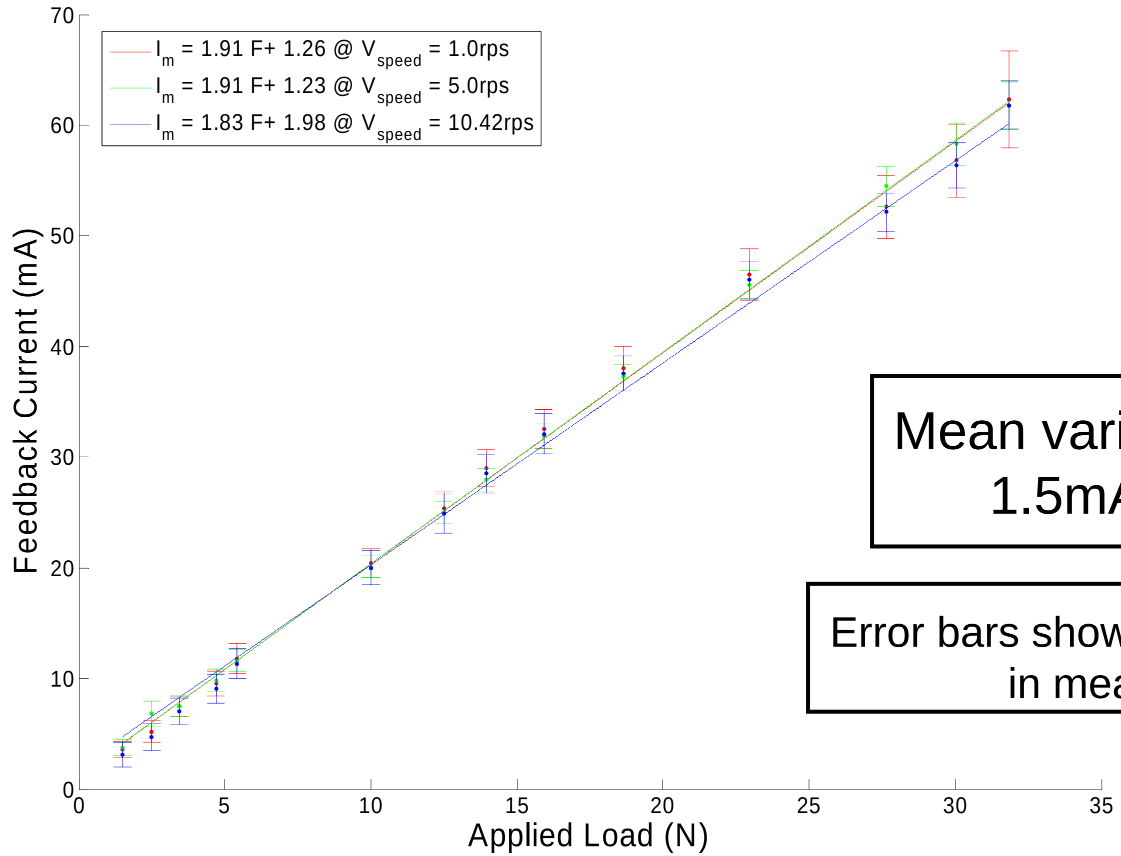
Current Limit Calibration



Experimental Setup



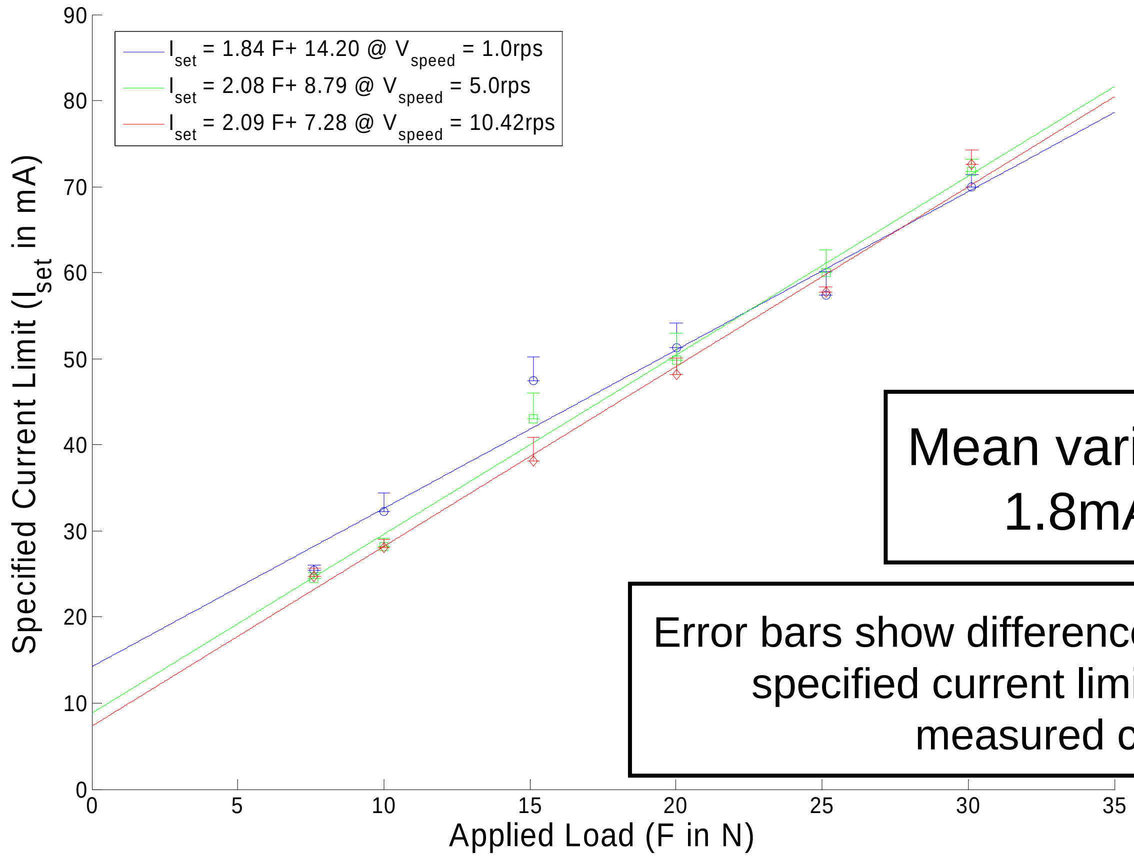
Current Feedback Performance



Mean variation:
1.5mA ≡ 0.8N

Error bars show deviation in measurement

Current Limit Performance



Mean variation:
1.8mA ≡ 0.9N

Error bars show difference between specified current limit (I_{set}) and measured current (I_m)

Discussion

- Motor current feedback allows us to measure applied load with < 1N resolution
  - Sufficient to control actuation redundancy
  - Works for non-backdriveable system as long as controller is attempting to move motor
- Power amplifier allows us to control applied force with < 1N resolution
  - Sufficient to avoid bucking of backbone

Future Work

- Develop model of backbone forces (and possibly of friction in transmission)
- Evaluate whether model and motor current feedback provide sufficiently accurate estimate of environmental forces
- Build and test complete snake unit (7 dof)
- Build and test complete 34-joint system