ELEC 341 – Electro-Mechanical Control Project

Project Part 1
System Identification

20 Marks

Develop a control system for a 3-finger gripper for grasping a spherical load.

The gripper uses a DC motor connected to a lead-screw to produce linear motion.

- *The motor consists of a rotor (rotating part) and stator (housing).*
- *The lead-screw consists of a screw and a nut.*
- *The nut is fixed, so rotating the screw causes the motor & screw to move back and forth.*
- *The combination of the motor and screw is called the actuator.*

Each finger consists of a stiff link, a stiff base and a flexible tine.

- *All fingers are symmetrical and move in unison.*
- *The link converts actuator translation into finger rotation.*
- *The flexible tines bend as the load is grasped to minimize damage to the load.*

Like most robots, the gripper is not LTI. The load impedance disappears when the load is released, and the link introduces a time-varying relationship between motor and finger angle speed. To get an LTI model, a fixed transmission ratio is calculated at a meaningful operating point and non-linearities are either approximated or ignored.

- *The operating point is when the tines first contact the load (see Figs 2, 4, 5).*
- *Each tine is assumed to remain connected to the load, even when the gripper opens.*
- *Link inertia is so small and so non-linear, it is neglected.*
- *Load mass is so small, it is neglected. This is not the total load mass, but rather the small element of mass that moves as the load is grasped and compressed (see Fig. 1).*
- *If the load was a very stiff object, like a walnut, its stiffness and damping could also be neglected. It this case the load is flexible, like a marshmallow, so stiffness and damping are included.*

The gripper shown in Fig. 1 consists of a motor, lead-screw, 3 fingers, and a load.

- *The lead-screw nut is the ground reference that is connected to the robot arm.*
- *The motor applies torque* ***τm*** *to the lead-screw screw.*
- *Friction between the motor rotor and stator is represented by angular damping* ***Bm****.*
- *The motor rotor has inertia* ***Jr*** *and the screw has inertia* ***Js****.*
- *For each unit of screw rotation, the screw translates a distance of* ***Ns****.*
- *Friction between the screw and nut is represented by linear damping* ***Bs****.*
- *The motor has Mass* ***Mm*** *and the screw has inertia* ***Ms****.*
- *For each unit of screw translation, the linkage rotates the fingers by* ***Nf****.*
- *The combined friction at joints "a", "b", and "c" is represented by angular damping* ***Bf****.*
- *Each finger has inertia* ***Jf*** *and each tine has negligible inertia.*
- *Each tine has angular stiffness of* ***Kt*** *and material damping* ***Bt****.*
- *For each unit of finger rotation, the tip of the tine translates a distance* ***Nt****.*
- *The element of load at each contact point has translational stiffness* ***Kl*** *and internal damping* ***Bl****.*

- *The rotor and screw rotate at a speed* ***ωr****.*
- *The actuator translates at a speed* ***va****.*
- *Each finger rotates at a speed* ***ωf****.*
- *Each tine tip and load element translate at an effective speed* ***vt****.*

The "System Model" has 3 transmissions and 4 coordinate frames shown in Fig. 3.

Rotor coordinates	*(rad, rad/s)*
Actuator coordinates	*(m, m/s)*
Finger coordinates	*(rad, rad/s)*
Tine coordinates	*(m, m/s)*

Actual geometry is shown in Fig. 4. and effective geometry is shown in Fig 5.

Fig. 1: Load

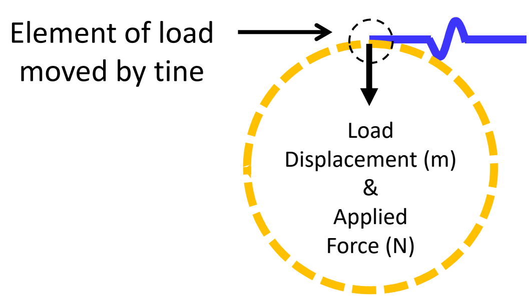


Fig. 2: Gripper

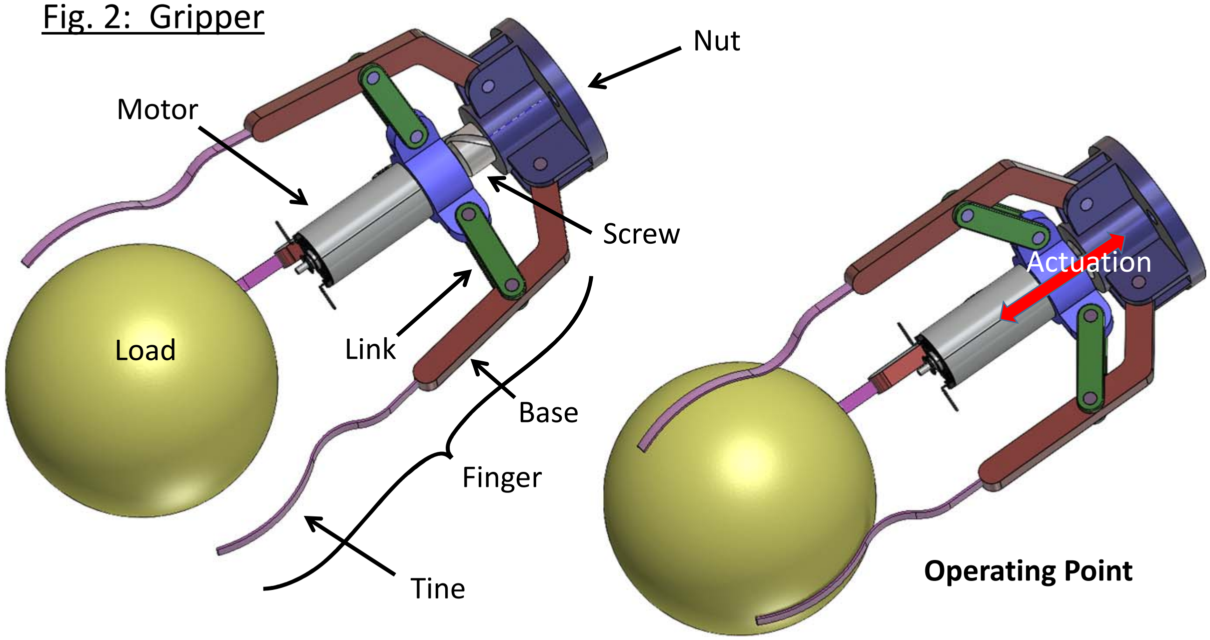
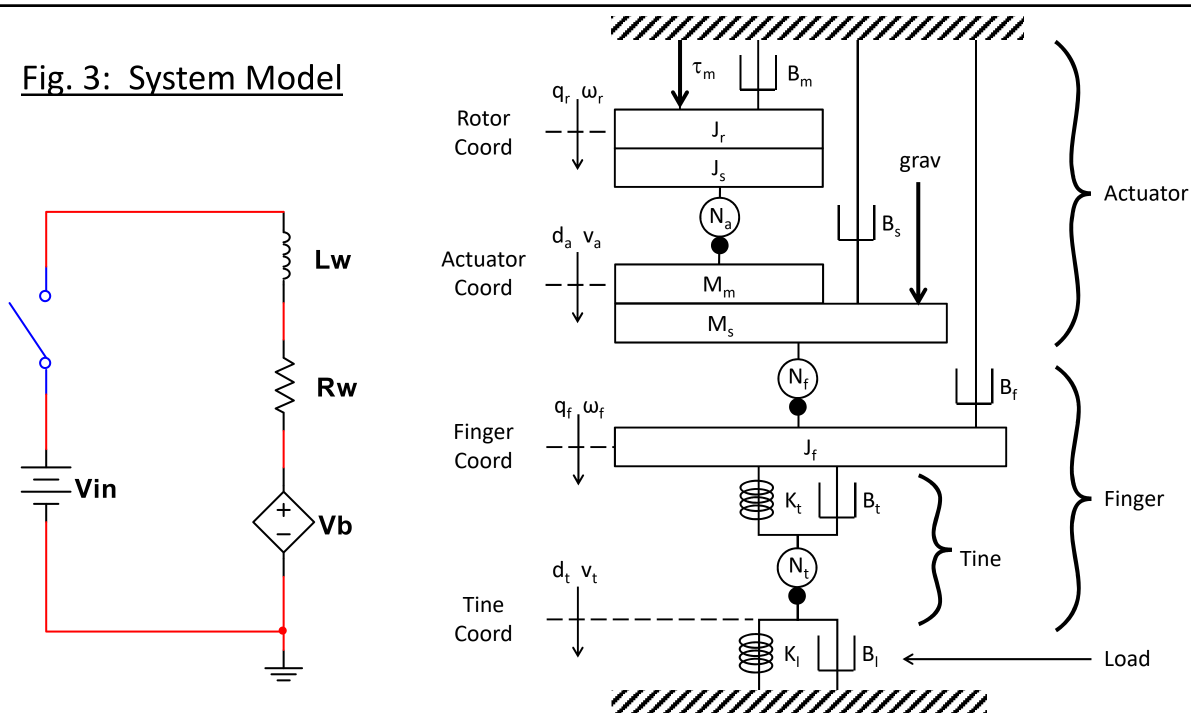


Fig. 3: System Model



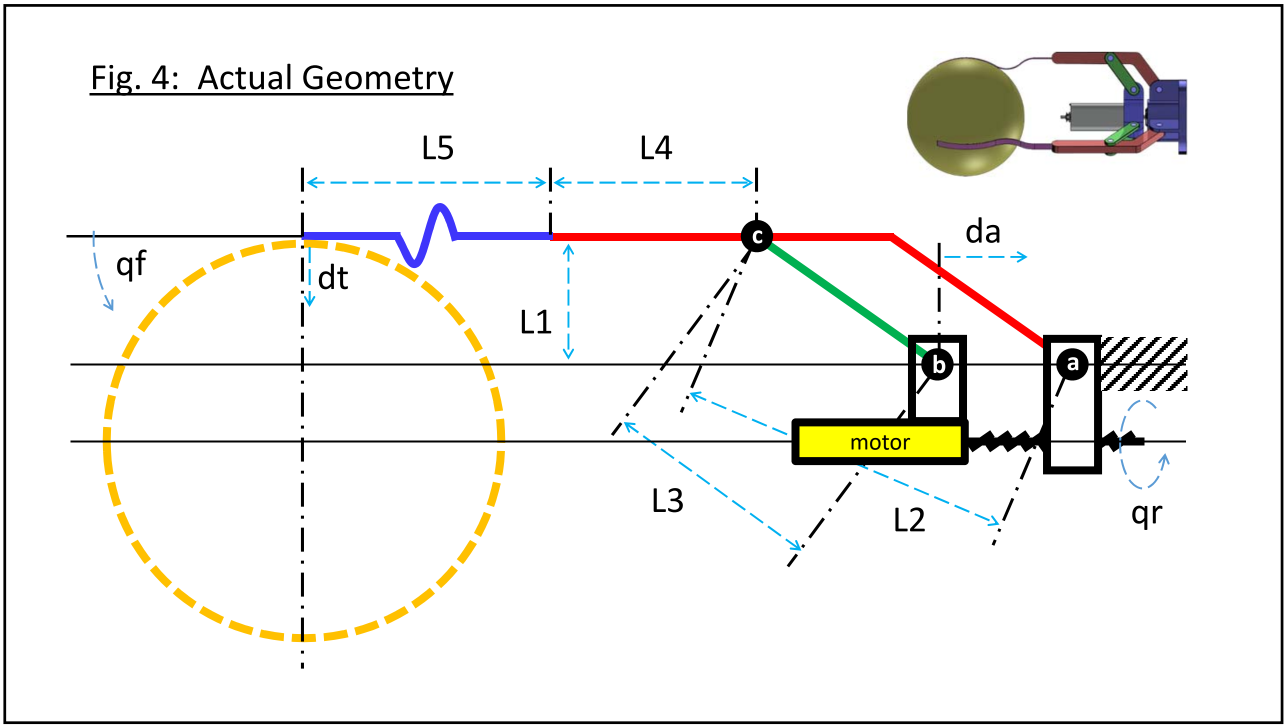


Fig. 4: Actual Geometry
L5
L4
qf
dt
L1
c
da
b
a
motor
L3
L2
qr

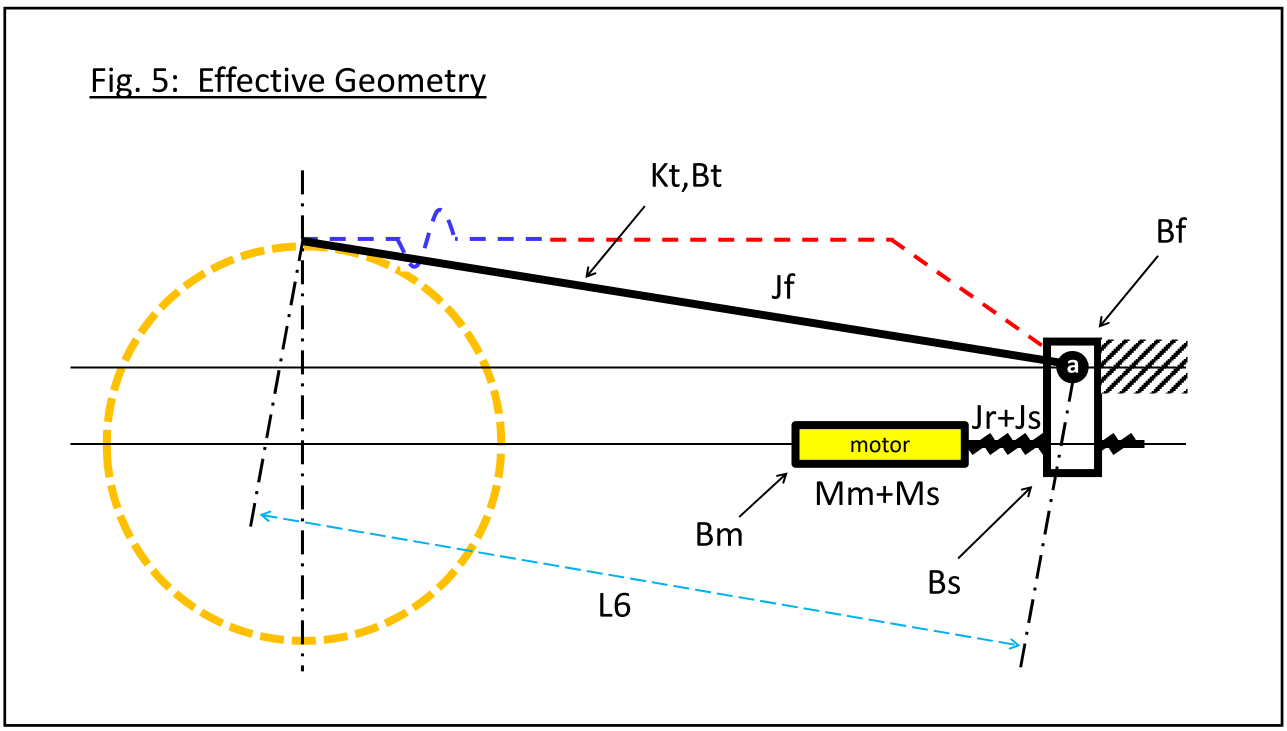


Fig. 5: Effective Geometry
Kt,Bt
Bf
Jf
a
Jr+Js
motor
Mm+Ms
Bm
Bs
L6

Actuator

Rw =	#A / 2	(Ω)
Lw =	#B x 30	(μH)
Km =	#C	(mNm/A)
Mm =	#D + #E	(g)
Bm =	#F / 30	(μNms)
Jr =	#G / 15	(g-cm^2)
Js =	#H / 5	(g-cm^2)
Ms =	#A / 4	(g)
Bs =	#B / 3	(Ns/m)*
Na =	3	(cm/turn)

Mechanism (per finger)

Jf =	#C / 3	(g-cm^2)
Bf =	#D	(mNms)
Nf =	10	(deg/cm)
Bt =	#E	(mNms)
Kt =	#F x 30	(mNm)
Nt =	from geometry	
Bl =	#G / 5	(Ns/m)
Kl =	#H x 15	(N/m)
L6 =	100	(mm)

** Translational Damping (note physical units)*

The motor voltage is supplied by an off-the-shelf (OTS) voltage amplifier which has an experimental step response in its data-sheet.

*Run **p1DSPlot.p** to plot the step response.*

*The experimental data was recorded using a DAQ with a fixed resolution. **Estimate** the continuous curve (input to the DAQ) which you can't see due to discretization error.*

Q1 2 mark(s) Black-Box Specs

Estimate Rise-Time Tr, Peak Time Tp, Settle Time Ts, and Percent Overshoot Pos.

- Q1.Tr (msec) Scalar
- Q1.Tp (msec) Scalar
- Q1.Ts (msec) Scalar
- Q1.Pos (%) Scalar

Q2 3 mark(s) 2nd Order Approx

Compute the 2nd order approximation that best approximates the raw data.

The approximation should provide a balance between rise and settle time by using the mean value of the associated natural frequencies.

- Q2.G (V/V) LTI

Motor angle is measured by an OTS position sensor with an internal processor for noise reduction. The data-sheet provides the equivalent Sensor Block Diagram shown in Fig 6.

*The data sheet indicates the output in (**mV**) but of course, the actual output of the sensor is in units of (**V**).*

*Use block diagram manipulation to find the transfer function **Hs = Kdc * D**.*

Q3 5 mark(s) Analog Position Sensor

Find Kdc:	DC Gain of sensor	
Find D:	Dynamics of sensor	
• Q3.Kdc	(V/deg)	Scalar
• Q3.D	(pure)	LTI

*A pole-zero plot **pzmap()** can be used to check if your transfer function is reasonable.*

You could also check the time constant of the step response.

You could also draw it as-is using Simulink and compare the response.

Analog position sensors are avoided in practice to because motors have no motion limit but circuits and voltage sensors always do have a voltage limit. Digital encoders are preferred.

This sensor is designed to output a reasonable value when the gripper moves a reasonable amount. Once you complete Part 1, make sure all values are REASONABLE for a gripper that is designed to picks up a small item like a walnut.

Fig. 6: Sensor Block Diagram

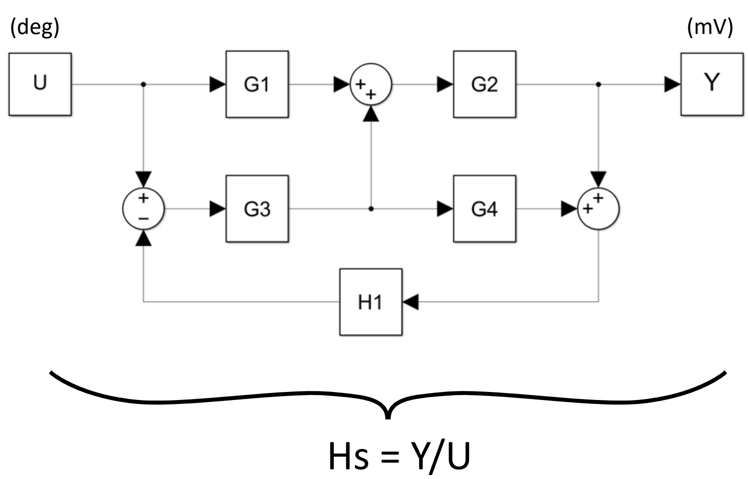
G1 = #Ax7/(s + #Bx800)

G2 = #Cx8/(s + #Dx700)

G3 = 10^5/(s + #Ex600)

G4 = #Fx50/(s + #Gx500)

H1 = 4/(s + #Hx5)



*Do all calculations (A & B matrices) in **rotor coordinates** since that is what the sensor measures. To show results in a different coordinate frame, include the corresponding coordinate transformation (transmission ratio) in the C and D matrices.*

*Neglect **Gravity**. It may be added later if the gripper is used in a vertical orientation.*

When gravity acts on a rotating object, it cannot be included in an LTI model due to the non-linear trig functions (sine, cosine). But when gravity acts on a translating object, it can be included by treating it like a force source. You just end up with a MIMO system.

COW: *Check your DC gains.*

If you apply a volt to the motor and wait a long time, does the rotor stop or keep spinning ???
What is the back-EMF ???
How much current flows ???
How much torque does the motor apply ???
How much force does the lead screw apply ???
How much torque does each finger apply ???
How much force does each tine apply to the load ???
What is the effective spring rate experienced by the finger ???
How much does the tine force displace the finger ???
How much is the actuator displaced ???
How much is the rotor displaced ???
What sensor voltage results ???

Are all of your numbers reasonable and do they match your plots ???

Find the corresponding transfer function for each of the following outputs.

IP = Motor voltage (V) in Q4-Q7.

Q4 2 mark(s) Motor Torque

Find G: OP = Motor torque (Nm) **Rotor** coordinates
- Q4.G (Nm/V) LTI

Q5 2 mark(s) Actuator Displacement

Find G: OP = Actuator displacement (m) **Actuator** coordinates
- Q5.G (m/V) LTI

Q6 2 mark(s) Finger Angle

Find G: OP = Finger angle (deg) **Finger** coordinates
- Q6.G (deg/V) LTI

Q7 2 mark(s) Tine Force

Find G: OP = Tine force (N/tine) **Tine** coordinates
- Q7.G (N/V) LTI

Q8 2 mark(s) Loop TF

Find GH: IP = **Amp** voltage (V) OP = Sensor signal (V)
- Q8.GH (V/V) LTI