Testing Materials for End Effector Surface

Nomenclature

$T = Tension\ in\ the\ cord$

$l = length\ of\ arm$

$m = mass$

$f = Frictional\ force$

$R_x = Horizontal\ Reaction\ Force$

$g = gravity$

$R_y = Vertical\ Reaction\ Force$

$\mu = Co - effecient\ of\ friction$

Aim:

To make a hypothesis to help decide the material to be used at the end effector based on the forces going through the arm at different angles of contact.

Equipment Needed:

- Suction hooks x2
- Drone and Weights x 5 in increments of 100g
- Cord
- Arm for attachment of end effector
- Rod to hang the drone

Setup:

1) Apply the suction hooks onto the surface that the test needs to be conducted on.
2) Attach the two ends of the cord to the arm and pass the rod through the loop created by the cord.
3) Place the rod on the suction hooks so that is the hinge for the system.

Make sure that the attachment points of the cord can move up and down the arm to allow a perpendicular attachment position in all cases.

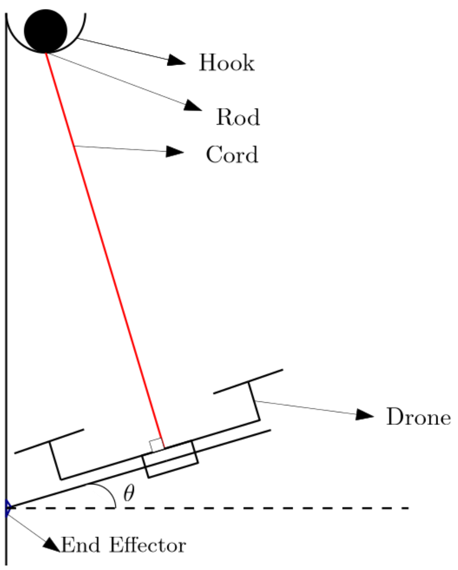

Figure 1 Setup

Hypothesis:

The weight attached results in a tension in the cord which replicates the thrust that the drone would create in practice. This thrust has a horizontal component and replicates the forces that the drone would create on the interacting surface. By moving the point of contact away from the hinge, we increase the angle at the hinge, hence, increasing the force. Due to the moments, there is always a downward pushing force on the surface, which needs to be counteracted by an upward force. Using the upward force as the frictional force and knowing the normal force to the wall, a prediction can be made with regards to the required coefficient of friction as shown below:

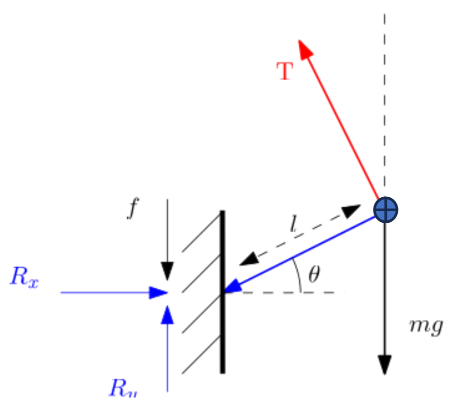

Figure 2 Free Body Diagram

$$Resolving\ in\ vertical\ direction : T\cos(\theta) + R_y = mg \tag{1}$$

$$Resolving\ in\ horizontal\ direction : T\sin(\theta) = R_x \tag{2}$$

$$Resolving\ moments\ about\ CoG : R_x l\sin(\theta) - R_y l\sin(\theta) = 0$$

$$\rightarrow\ R_x\sin(\theta) = R_y\cos(\theta) \tag{3}$$

$Sub\ (2)\ in\ (3)$

$$T\sin^2(\theta) = R_y\cos(\theta) \qquad \rightarrow \qquad \frac{T\sin^2(\theta)}{\cos(\theta)} = R_y \tag{4}$$

$Sub\ (4) in\ (1)$

$$T\cos(\theta) + \frac{T\sin^2(\theta)}{\cos(\theta)} = mg \qquad \rightarrow \qquad T\cos^2(\theta) + T\sin^2(\theta) = mg\cos(\theta)$$

$$T = mg\cos(\theta) \tag{5}$$

$Sub\ (5)\ in\ (2)$

$$R_x = mg\cos(\theta)\sin(\theta) \tag{6}$$

$Sub\ (6)\ in\ (3)$

$$R_y = mg\sin^2(\theta) \tag{7}$$

The contact point is stationary, so the R_y is equal to the frictional force

$$f = R_y \qquad \rightarrow \qquad \mu N = R_y$$

$$\mu mg\cos(\theta)\sin(\theta) = mg\sin^2(\theta) \qquad (N = R_x)$$

$$\mu = tan(\theta) \tag{8}$$

Verification:

1) Apply the first material at the end of the end effector.
2) Fix the angle made by the end effector and the horizontal to 10^0. If the end effector stays stationary, consider the test pass.
3) Repeat the test at $20^\circ, 30^\circ, 35^\circ, 40^\circ$ and 45° or the limit angle of the end effector, whichever comes first, and record for pass or failure.
4) Change the material at the end effector and repeat steps 2 and 3.

Outcome:

Since the coefficient of friction of the material used at the end effector is known, calculated predictions can be made regarding when the end effector will start to slip. By doing the above test, these predictions can be verified.

The normal force can be written as a known constant (mg) multiplied with a variable, k $[\sin(\theta)\cos(\theta)]$ which is a function of θ. This function has been plotted in Figure 3. The conclusion can be made that the maximum normal force that can be achieved is half the weight attached and that this force is experienced at $\theta = 45°$. Since the horizontal force is the required force, the limit can be set to $45°$.

From Eq.8, it is known that the coefficient of friction is also a function of the angle. Using the limit defined previously, the maximum required coefficient of friction is 1.

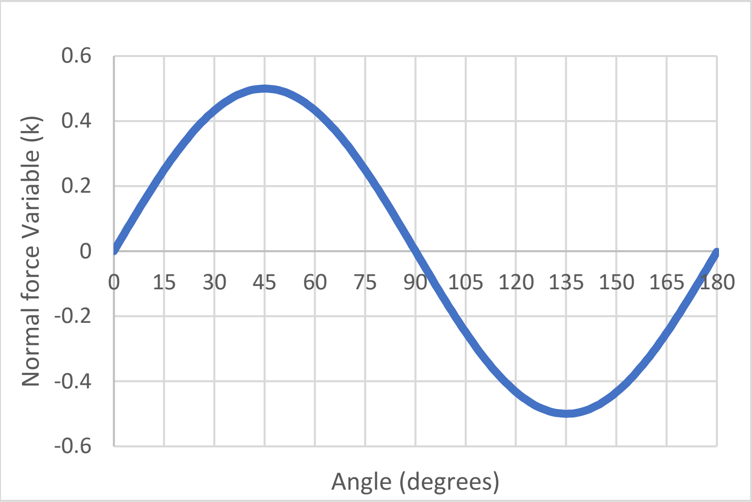

Figure 3 Force Characterisation

Material	Coefficient of friction	Predicted max angle	Experiment max angle	Outcome