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Hip and Ankle Motor Selection for the Next Generation of Ranger Robot

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Biorobotics and Locomotion Lab

Cornell University

I. Introduction

One of the objectives of the Biorobotics and Locomotion Lab is to build long-ranged energy efficient robots. We aim to minimize the power consumption, while maximizing the robots' walking range. An efficient mechanical design and carefully chosen combination of parts enable us to achieve this objective. Likewise, the electronics parts have to be designed or chosen properly.

In order to achieve a long range walking robot, it is crucial that we choose the right combination of motors and gear boxes. This gives rise to my research, which explores and identifies the appropriate combination of motors and gear boxes to be used as hip and ankle motors for the next generation of Ranger robot. This robot will employ a new 'nervous' system and more degrees of freedom.

II. Method and result

To maximize energy efficiency, the properties of the motor have to correspond to the functions and needs of the robot. After consulting with Professor Ruina and Jason Cortell, I have established that the desired no-load speed should be approximately 100 rpm and stall torque of the motor and gear box of hip and ankle should be 6 N.m and 12 N.m respectively. 6 N.m comes from the approximation made by mechanical team deciding that we want stall torque of the hip motor to be higher than what ranger currently has which is 4.5 N.m Likewise, the ankle motor of the new robot(assume 2 legs) is expected to have stall torque around 12 N.m since this required amount is for the robot to be able to push off and is described in the following equation.

Torque required by ankle motor = weight of the robot*length of the foot (1)

Where the expected length of the foot and weight of the robot are about 0.1 m and 120 N respectively. In order to identify the pairs of motor and gearbox that meet the two criteria mentioned above, a power- based or torque-independent comparison should be used since each pair will have different gear ratios.

Table 1: pairs of motors and gearboxes that satisfy no load speed around 100 rpm.

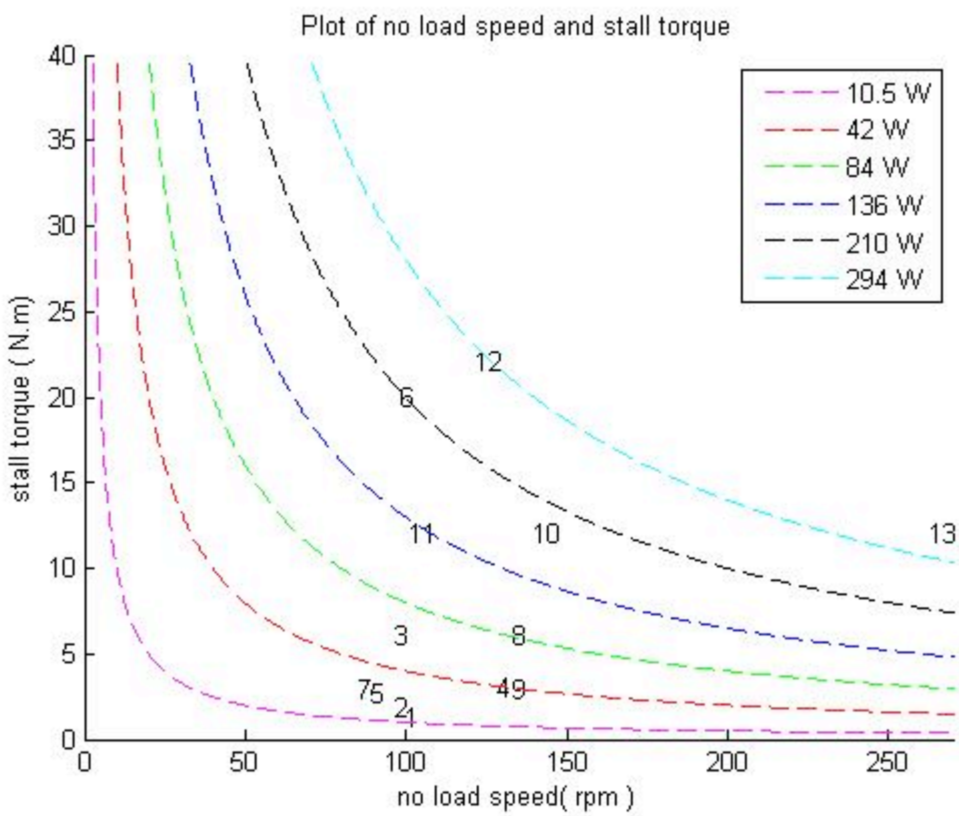
Number	Motor + gearbox	Max rpm	Stall torque (N.m)	Total efficiency(%) (Best case)	No load power (w)	Weight (Kg)	Nominal Voltage(V)
1	Faulhauber series 2657 cr(coreless) + 26A(64:1)	100	1.2	62.05	1.38	0.179	12
2	Faulhauber series 2657 cr(coreless) +26/1(66:1)	96.96	1.8	59.5	1.38	0.295	12
3	Faulhauber series 2657 cr(coreless)+30/1(66:1)	96.96	6	59.5	1.38	0.327	12
4	Faulhauber series 3257 cr(coreless)+32/1 (46:1)	128.26	3	62.25	3.096	0.452	12
5	Fauhauber series 3257 cr(coreless)+32/3(66:1)	89.4	2.6	58.1	3.096	0.472	12
6	Fauhauber series 3257 cr(coreless)+38A(60:1)	98.3	20	74.7	3.096	0.572	12
7	Faulhauber series 3257 cr(coreless)+38/1,38/2(66:1)	89.4	2.9	58.1	3.096	0.51	12
8	Faulhauber brushless DC motor servomotors 3564-12B + 30/1(66:1)	133.18	6	56.7	2.472	0.481	12
9	Faulhauber brushless DC motor servomotors 356412B +38/1,38/2(66:1)	133.18	2.9	56.7	2.472	0.578	12
10	maxon RE 35 Ø35 mm, Graphite Brushes, 90 Wat+ GP32(86:1)	139.5	12	58.87	3.69	0.534	15
11	maxon EC-max 30 Ø30 mm, brushless 60 Watt+ GP32(66:1)	101.139	12	56.98	3.216	0.484	12
12	maxon EC-max 40 Ø40 mm, brushless, 70 Watt+GP42(66:1)	121.66	22	54.576	7.584	0.85	12
13	Banebots MP 36064-540 with 64:1	263	17.84	n/a	12	0.36	7.2

Note:1. all data taken from specification sheets which are in appendix section

2. Number 13 corresponds to cheap motor which costs 42 dollars

3. Graphs and definitions of data can be found in the following pages

Graph 1 plot of no load speed and stall torque



Numbers in graph 1 correspond to numbers given to pairs of gear boxes and motors in table 1. The dash line correspond to lines of constant power. The higher the position of the line, the more constant power they have. These lines are described in the following equation.

$$(\text{No load speed} * \text{stall torque})/4 = \text{constant} \quad (2)$$

Stall torque is the torque produced by the motor when at standstill.
No load speed is the speed at which the motor turns at nominal voltage and without load. It is approximately proportional to the applied voltage.
Constant is equal to peak power value

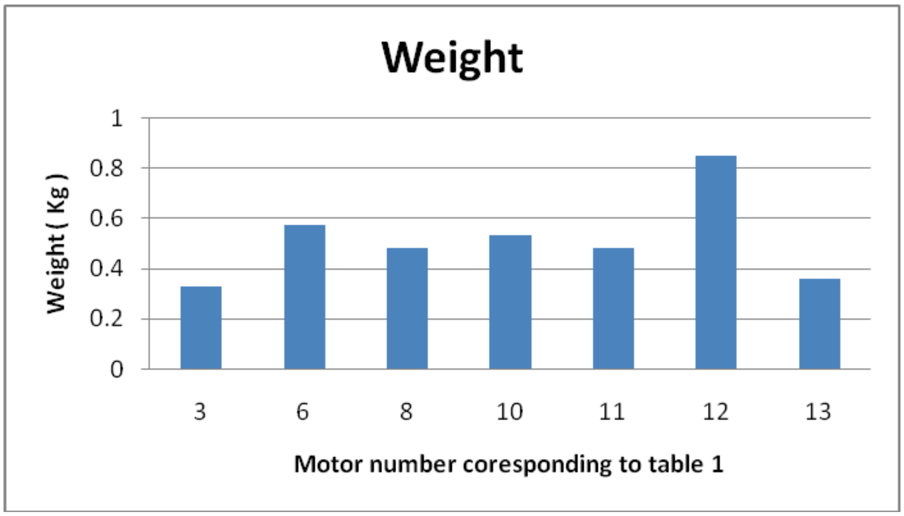
From graph one, for hip motor which requires stall torque to be around 6 N.m, we have 3 and 8 as candidates.

Likewise, for ankle motor which requires torque around 12 N.m, we can rank motor corresponding to number given in table 1 from least to most powerful as 11,10,6,12,13

A. Weight

The weight of the motor and gearbox is also a major constraint for a new generation of Ranger, a long range robot. As evident in graph 2, the heaviest and the lightest motor and gear box combinations exhibit nearly 0.5 kg difference.

Graph 2 Weight of motors and gearboxes



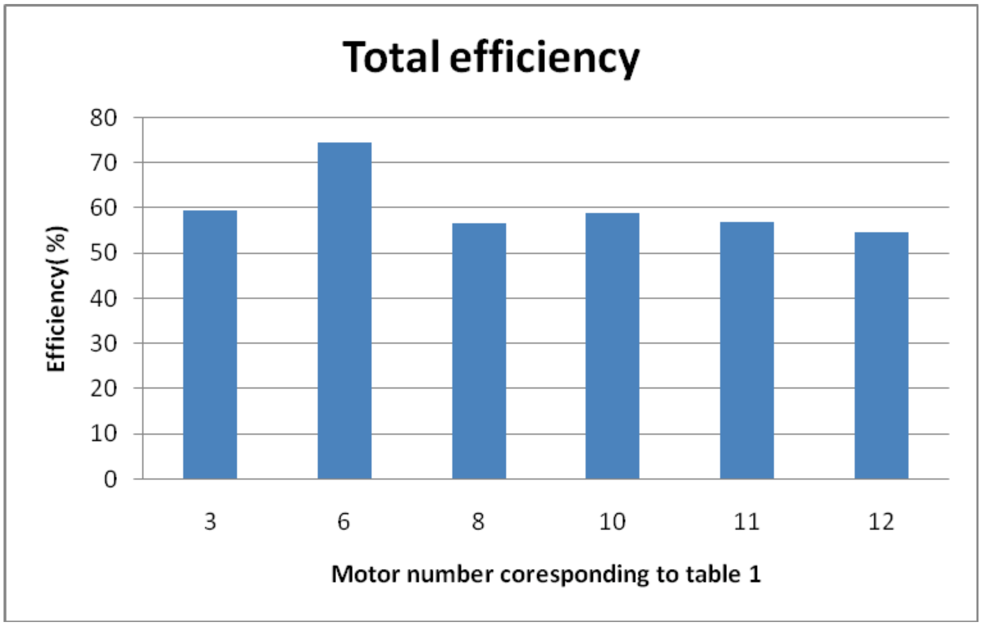
Number 12, which corresponds to Maxon EC-max 40 Ø40 mm, brushless, 70 Watt(66:1) is the heaviest of all. Thus, number 12 can be eliminated from hip and ankle motor candidates.

B. Total Efficiency

Like weight, the total efficiency is also a major constraint and very crucial for the power used in a long range robot. We can see from graph 3 that number 6 ,which corresponds to Faulhauber series 3257 cr(coreless) with 38A(60:1), has the highest

$$\text{Total Efficiency} = \text{Efficiency of Gearbox} * \text{Efficiency of Motor} \tag{3}$$

Graph 3 Total efficiency



C. No load power

No load power is the power required to operate a motor without attaching load to it. Thus, the lower value of no load power, the better the motor. The assumption I made here is that all the power from the motor passes through the gearbox to the load, without any energy lost along the way. This allows for a comparison of no load power, which is independent of gear box ratio.

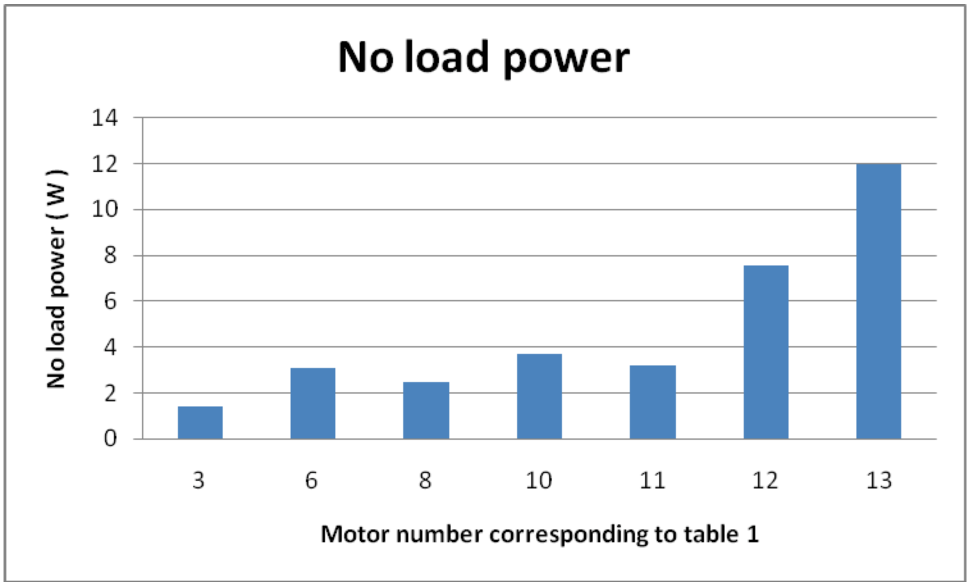
No load power = Nominal voltage * No load current (4)

Where Nominal voltage is the DC voltage connecting to the motor

No load current is the current the unloaded motor draws when running at no load speed

From graph 4, we can clearly see number 3 which corresponds to Faulhauber series 2657 cr(coreless) with 30/1(66:1) gear box has the least no load power.

Graph 4 No load power



Conclusion

For the ankle motor, from graph 1, we have number 6,10,11 and 13 as candidates. However, after consulting with electrical team, we agree that DC motors are preferred to AC motors since the latter part will need extra electronics components to convert DC voltage from battery to AC. Thus, number 11which is a AC motor can be eliminated. From efficiency graph, number 6 has the highest efficiency while having lower no load power than number 10 and 13. Likewise, from graph 1, number 6 has higher power and also has closer speed value to 100 rpm than number 10. **Thus, for ankle motor, the recommended is number 6 which corresponds to Fauhauber series 3257 cr(coreless) with 38A(60:1) gear box**

For hip motor, we have 3 and 8 as candidates. From weight graph, motor number 3 is lighter than motor number 8. Moreover, from no load power graph, motor number 3 has lower no load power than motor number 8 by 44%. **Thus, motor number 3 which is 2657 cr(coreless) with 30/1(66:1) gear box is preferred.**

Appendix

Faulhauber series 2657 cr(coreless)

http://www.faulhaber-group.com/uploadpk/EN_2657CR_DFF.pdf

With 26A(64:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_261_MIN.pdf

With 26/1(66:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_301_MIN.pdf

With 30/1(66:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_301_MIN.pdf

Faulhauber series 3257 cr(coreless)

http://www.faulhaber-group.com/uploadpk/EN_301_MIN.pdf

With 32/1 (46:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_321_DFF.pdf

With 32/3(66:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_323_MIN.pdf

With 38A(60:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_38A_DFF.pdf

With 38/1,38/2(66:1)

http://www.faulhaber-group.com/uploadpk/EN_381_382_MIN.pdf

Faulhauber brushless DC motor servomotors 3564-12B

http://www.faulhaber-group.com/uploadpk/EN_3564B_MIN.pdf

With 30/1(66:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_3564B_MIN.pdf

With 38/1,38/2(66:1) gear box

http://www.faulhaber-group.com/uploadpk/EN_381_382_MIN.pdf

maxon RE 35 Ø35 mm, Graphite Brushes, 90 Watt

http://shop.maxonmotor.com/ishop/article/article/273753.xml

With GP32 (86:1) gear box

http://shop.maxonmotor.com/ishop/article/article/326667.xml

maxon EC-max 30 Ø30 mm, brushless 60 Watt

http://shop.maxonmotor.com/ishop/article/article/272762.xml

With GP32(66:1) gear box

http://shop.maxonmotor.com/ishop/article/article/326665.xml

maxon EC-max 40 Ø40 mm, brushless, 70 Watt

http://shop.maxonmotor.com/ishop/article/article/283867.xml

With GP42(66:1)

http://shop.maxonmotor.com/ishop/article/article/203122.xml

Citations

www.faulhauber –group.com

www.maxonmotorusa.com