Lab Assignment: Lab 4: The Human Arm

Title Author: Misbah Ahmed Nauman

CCID: misbahah

Student ID: 1830574

Lab Partner(s): Zeeshan

EN PH 131, ET23

TA: Kiril Kolevski

Date of Lab: 03/05/2024

Question 1:

From the lab manual[1],

$$m_T d_1 \sin(\theta) - m_L(d_1 + d_2 + d_3) - m_A(d_1 + d_2) = 0 \quad \textbf{Eq. 4.1}$$

$$\sum F_x = 0 \text{ and } \sum F_y = 0 \quad \textbf{Eq. 4.2}$$

$$T = m_T g \quad \textbf{Eq. 4.3}$$

$$d_1 = (2.35 \pm 0.05)\text{ cm}$$
$$d_1 + d_2 = (14.5 \pm 0.1)\text{ cm}$$
$$d_1 + d_2 + d_3 = (24.0 \pm 0.1)\text{cm}$$

To calculate the mass of the arm, m_A, we first had to find m_T. This was determined by adding known masses to balance the arm when $\theta = 90°$ and $m_L = 0$. The value of m_T equals that of the mass added, and the uncertainty for m_T was found by determining the range of masses for which the arm was level and taking the average of those values. Experimental value of m_T came out to be $m_T = (1820 \pm 10)$g. We can now calculate the mass of the arm, m_A, using **Eq. 4.1**.

$$(1820)(2.35)\sin(90) - 0 - m_A(14.5) = 0$$

$$m_A = 295 \text{ g}$$

For uncertainty in m_A,

$$\delta m_A = \sqrt{\left(\frac{\partial m_A}{\partial m_T}\right)^2 (\delta m_T)^2 + \left(\frac{\partial m_A}{\partial d_1}\right)^2 (\delta d_1)^2 + \left(\frac{\partial m_A}{\partial (d_1 + d_2)}\right)^2 \left(\delta(d_1 + d_2)\right)^2}$$

$$\delta m_A = 6.07$$

Therefore,

$$m_A = (295 \pm 6)\text{g}$$

Question 2:

For $\theta = 50°$, $m_L = 0$ g, using **Eq. 4.1**,

$$m_T(2.35)\sin(50) - 0 - 295(14.5) = 0$$

$$m_T = 2380 \text{ g}$$

Therefore, theoretical value for $m_T = 2380$ g.

The experimental value of m_T was found to be $m_T = 2400$ g. The uncertainty for m_T was found to be 50 g. This was done by determining the range of masses for which the arm was level and taking the average of those values.

Therefore, experimental value for $m_T = (2400 \pm 50)$g.

Since the theoretical and experimental values for m_T are within 1 error interval, there is **good agreement** between them.

Question 3:

For $\sum F_x = 0$, using **Eq. 4.2** and **Eq. 4.3**,

$$F_E x = T\cos(\theta) = m_T g\cos(\theta) = \frac{1400}{1000} \times 9.81\cos(50) = 15.1 \text{ N}$$

For $\sum F_y = 0$, using **Eq. 4.2** and **Eq. 4.3**,

$$F_Ey = T\sin(\theta) - m_Ag - m_Lg = m_Tg\sin(\theta) - m_Ag - m_Lg$$

$$= \frac{2400}{1000}(9.81\sin(50)) - \frac{295}{1000}(9.81) - 0 = 15.1 \text{ N}$$

Now,

$$F_E = \sqrt{(F_Ex)^2 + (F_Ey)^2} = \sqrt{(15.1)^2 + (15.1)^2} = 21.4 \text{ N}$$

Hence, F_E = 21.4 N.

Question 4:

For $\theta = 50°$, m_L = 100 g, using **Eq. 4.1**,

$$m_T(2.35)\sin(50) - 100(29) - 295(14.5) = 0$$

$$m_T = 3990 \text{ g}$$

Therefore, theoretical value for m_T = 3990 g.

The experimental value of m_T was found to be m_T = 3950 g. The uncertainty for m_T was found to be 50 g. This was done by determining the range of masses for which the arm was level and taking the average of those values.

Therefore, experimental value for $m_T = (3950 \pm 50)$g.

Since the theoretical and experimental values for m_T are within 1 error interval, there is **good agreement** between them.

F_E can be calculated using the same steps used in **Question 3**, except instead of $m_L = 0$ g, we take $m_L = 100$ g, and we take $m_T = (3950 \pm 50)$g.

For $\sum F_x = 0$, using **Eq. 4.2** and **Eq. 4.3**,

$$F_Ex = T\cos(\theta) = m_Tg\cos(\theta) = \frac{3950}{1000} \times 9.81\cos(50) = 24.9 \text{ N}$$

For $\sum F_y = 0$, using **Eq. 4.2** and **Eq. 4.3**,

$$F_Ey = T\sin(\theta) - m_Ag - m_Lg = m_Tg\sin(\theta) - m_Ag - m_Lg$$

$$= \frac{3950}{1000}(9.81\sin(50)) - \frac{295}{1000}(9.81) - \frac{100}{1000}(9.81) = 25.8 \text{ N}$$

Now,

$$F_E = \sqrt{(F_Ex)^2 + (F_Ey)^2} = \sqrt{(24.9)^2 + (25.8)^2} = 35.9 \text{ N}$$

Hence, F_E = 35.9 N.

Without the load ($m_L = 0$ g), m_T = 2400 g. With the load ($m_L = 100$ g), m_T = 3950 g. Therefore, value of m_T increased by a factor of 1.65 by adding the load.

Without the load ($m_L = 0$ g), F_E = 21.4 N. With the load ($m_L = 100$ g), F_E = 35.9 N. Therefore, value of F_E increased by a factor of 1.68 by adding the load.

Question 5:

For $\theta = 130°$, $m_L = 0$ g, using **Eq. 4.1**,

$$m_T(2.35)\sin(130) - 0 - 295(14.5) = 0$$

$$m_T = 2380 \text{ g}$$

Therefore, theoretical value for m_T = 2380 g.

The experimental value of m_T was found to be m_T = 2440 g. The uncertainty for m_T was found to be 100 g. This was done by determining the range of masses for which the arm was level and taking the average of those values.

Therefore, experimental value for $m_T = (2440 \pm 100)$g.

Since the theoretical and experimental values for m_T are within 1 error interval, there is **good agreement** between them.

Question 6:

The theoretical values for m_T were the same for $\theta = 50°$ and $\theta = 130°$. However, the experimental value for m_T and its uncertainty was higher for $\theta = 130°$. It can be concluded that the arm was less stable at larger angles.

A reason for this could be that at shorter angles, the bicep and arm are closer together, which improves stability. When the angle increases, the distance between the forearm and bicep also increases that leads to an unstable system.

Question 7:

This model serves as a reliable representation of the human arm, as our observed results consistently aligned well with the expected values. The agreement between experimental and theoretical values remained within a single error interval throughout, reflecting an accurate approximation. However, at larger angles when the distance between the bicep and forearm increased, the results were inaccurate and had significant errors. Consequently, the accuracy of the approximation proved more effective for smaller angles than for larger ones.

A possible reason for the uncertainty in m_T could be due to friction in the elbow joint, and the instability of the arms when experiment was performed for larger angles.

To minimize the uncertainty in m_T, a lubricating oil could be used in the joints to avoid friction. This would give a more precise answer for uncertainty since the arm would be tipped over for smaller change in masses.

Question 7:

References

[1] *Lab Manual EN PH 131*. Edmonton: University of Alberta, Department of Physics.

Acknowledgements

I would like to express my gratitude to my lab partner, Zeeshan, for his invaluable assistance in helping perform the experiment by adding different weights to the arm, and stabilizing the arm when large weights were added. Additionally, I extend my appreciation to our lab Teaching Assistant, Mr. Kiril Kolevski, for providing consistent guidance and support throughout the entire laboratory experiment.