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*Lab Report in Physics*

# Preliminary Model of Energy Harvesting through Prosthetics

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**Abstract**: The goal of the paper is to harvest energy through the flexing of a piezoelectric unit in a prosthetic limb. Depending upon the flex of the sensor, it produces a voltage output. To embed this in a forearm prosthetic, a piezoelectric sensor can be attached to the hinge joint. Hence, the more it moves, the more voltage output is produced. In this paper, a prosthetic limb is modeled as a physical pendulum. The experiment done includes a voltmeter, a physical pendulum, and a piezoelectric sensor attached to the axis. Due to the formula breakdown into a 2-parameter model, the chi-squared analysis on the formula is much simpler. Hence, the author could fit the model to the data and the best fit values were found.

**Keywords**: Energy harvesting, Piezoelectric sensor, Voltage output, Angle

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## 1. Introduction

Electricity has emerged as the most used energy form in this technological era. While we find innovative and inexpensive ways to produce electricity, it is also important to harvest the energy that is wasted unintentionally. Applying this to prosthetics, an enhanced piezoelectric sensor can be fixed on the hinge joint such that the sensor flexes as the joint moves. This can result in battery life extension; the more the joint is moved, the longer is the battery life.

This research paper focuses on energy harvesting through prosthetics because limb prosthetics possess a hinge joint that contracts and expands regularly. Also, due to environmental constraints, this can be a good experiment because it is comparatively easier to set up at home. On a larger scale, this can be used in energy generation to harvest the minute energy quantities that are wasted; this increases the efficiency of electricity generation. There are many applications of energy harvesting beyond these examples.

Aside from the energy harvesting, the paper also focuses on fitting a model to provide the voltage output formed through the flexed angle. The layout of the paper is as follows:

1. Research Design, Data collection and analysis Methods, Materials
2. Mathematical Model
3. Chi-squared Analysis
4. Final Results & Conclusions
5. References

**2. Research Design, Data collection and analysis Methods, Materials**

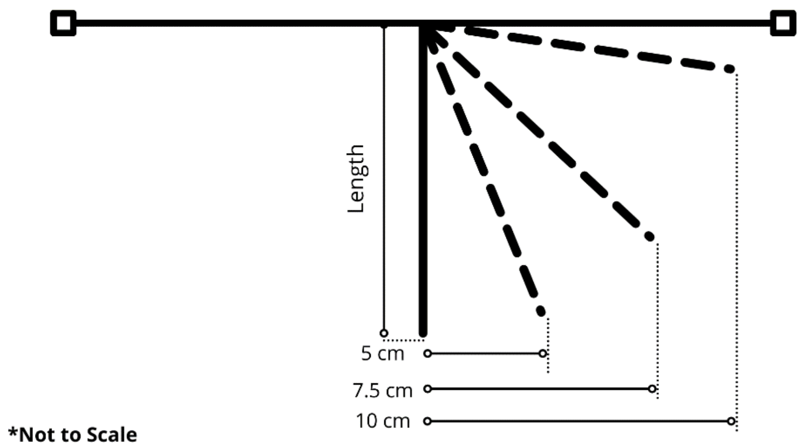
The experiment consisted of the following:

2.1 Physical pendulum with the following properties:

a. Weight: 208 g
b. Dimensions: 29.5 cm x 2.5 cm x 0.4 cm
c. Length: 29 cm from the axis

2.2 A piezoelectric sensor at the axis of the physical pendulum for it to bend at the following displacements:

- 5cm
- 7.5cm
- 10cm




2.3 To find the angle formed from the displacements above, the below formula was used:

$\Theta$ = arctan (displacement/length).

The Results were as follows: -

- 5 cm resulted in $\Theta = 0.171$
- 7.5 cm resulted in $\Theta = 0.253$
- 10 cm resulted in $\Theta = 0.332$

2.4 A multi-meter that showcased the voltage output with the changing displacements. For each displacement, 3 values were measured in millivolts. These values are as follows:

- For 5 cm: 5.5 mV, 6 mV, 6.1 mV
- For 7.5 cm: 13.8 mV, 13.9 mV, 14.4 mV
- For 10 cm: 26.5 mV, 28.1 mV, 26.2 mV

## 3. Mathematical Model

With the results, it is evident that a certain voltage output was produced when there is flex in the piezoelectric sensor at a particular angle. For the sake of simplicity, the voltage was taken to be a power law in θ (the angle). So, the following mathematical formula could be considered:

$V_{OUT} = K\theta^n$, where θ is in radians, and K and n are constants,

$\text{Log } V_{OUT} = n \text{ Log } \theta + \text{Log } K$.

Here, a 2-parameter model is obtained. Due to this, the usage of chi-squared analysis is much simpler. Also, now this is a linear model because it is in the form of $Y = Ax + B$ where,

$Y = \text{Log } V_{OUT}$,

$n = A$,

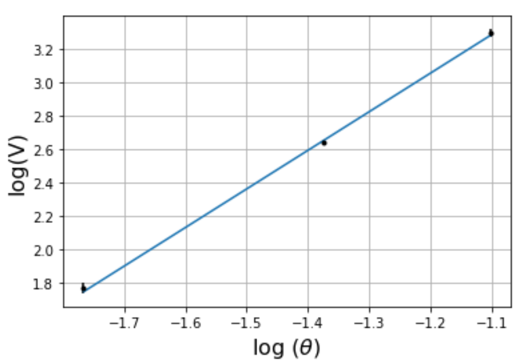
$\text{Log } \theta = x$,

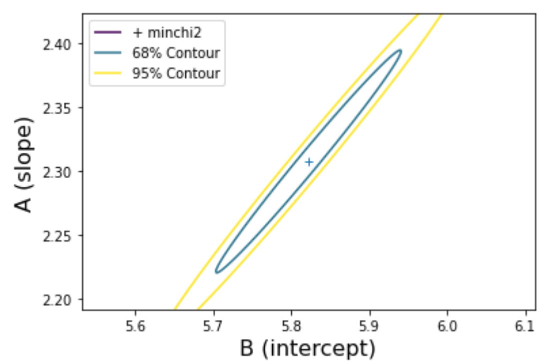
$\text{Log } K = B$.

## 4. Chi-squared Analysis (Carey & Zengel, 2019)

To perform a chi-squared analysis of the data, a python script (Witkov & Zengel, 2021) was used. The code is the intellectual property of Dr. Carey Witkov and Keith Zengel, and the author Vyom Sachan does not hold any credit for it.

## 5. Final Results & Conclusions




CHI-SQUARED ANALYSIS RESULTS

A_best = 2.31,
B_best = 5.82,
minchi2 = 1.50,
n = 2.31,
N = 3,
minchi2 good fit range = [0.55, 5.45 ].

The final results have been mentioned below:

1. It is noticeable that, $n = 2.31 = A_{Best}$.
2. Also, $B_{Best} = \text{Log } K = 5.82$,

   Therefore, $K = 10^{B\_Best} = 10^{5.82}$,

   Hence, K = 660693.448 millivolts.

The Final Formula:

$$V_{OUT} = K\theta^{n},$$

$$V_{OUT} = (660693.448) * \theta^{2.31}.$$

It is assumed that there is no uncertainty in the independent variable (angle i.e., θ) that can be controlled and set exactly. The uncertainty in the fit-parameters is given in the 68% and 95% contours.

**References:**


Witkov, C., & Zengel, K. (n.d.). *scripts/energy_harvesting_prosthetic.ipynb at master · witkov/scripts*. GitHub. https://github.com/witkov/scripts/blob/master/energy_harvesting_prosthetic.ipynb

Witkov, C., & Zengel, K. (2019). *Chi-Squared Data Analysis and Model Testing for Beginners* (Illustrated ed.). Oxford University Press.