The Motion of Standing: Modeling Balance with Stochastic Processes

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Introduction

The means by which the human body remains balanced are both complicated and subtle. Successfully understanding this behavior allows us to approach problems involving posture in medicine and robotics. We investigate human postural control by studying the motion of the body's center of pressure. Previous work by the neuromuscular researchers Collins and De Luca established a model for this motion based on a bounded random walk, i.e. a simple random process. Like this previous work we use stochastic processes to develop a new model. However, our model aims to be fundamentally simpler in form and application.

The Center of Pressure

- The Center of Pressure (COP) is the point of application of the body's net weight vector on the floor.
- As our weight shifts, so does the COP.
- We used a force plate to record the COP trajectory of healthy individuals attempting to remain stationary.
- Analysis of the COP trajectories revealed features that informed the model.

Stochastic Processes

- In stochastic systems, the future states of the system are determined probabilistically.
- A stochastic process uses one or more random elements to describe the evolution of the system over time.
- A classic stochastic process is a random walk.
- Another frequently used stochastic process is Gaussian white noise (ξ).

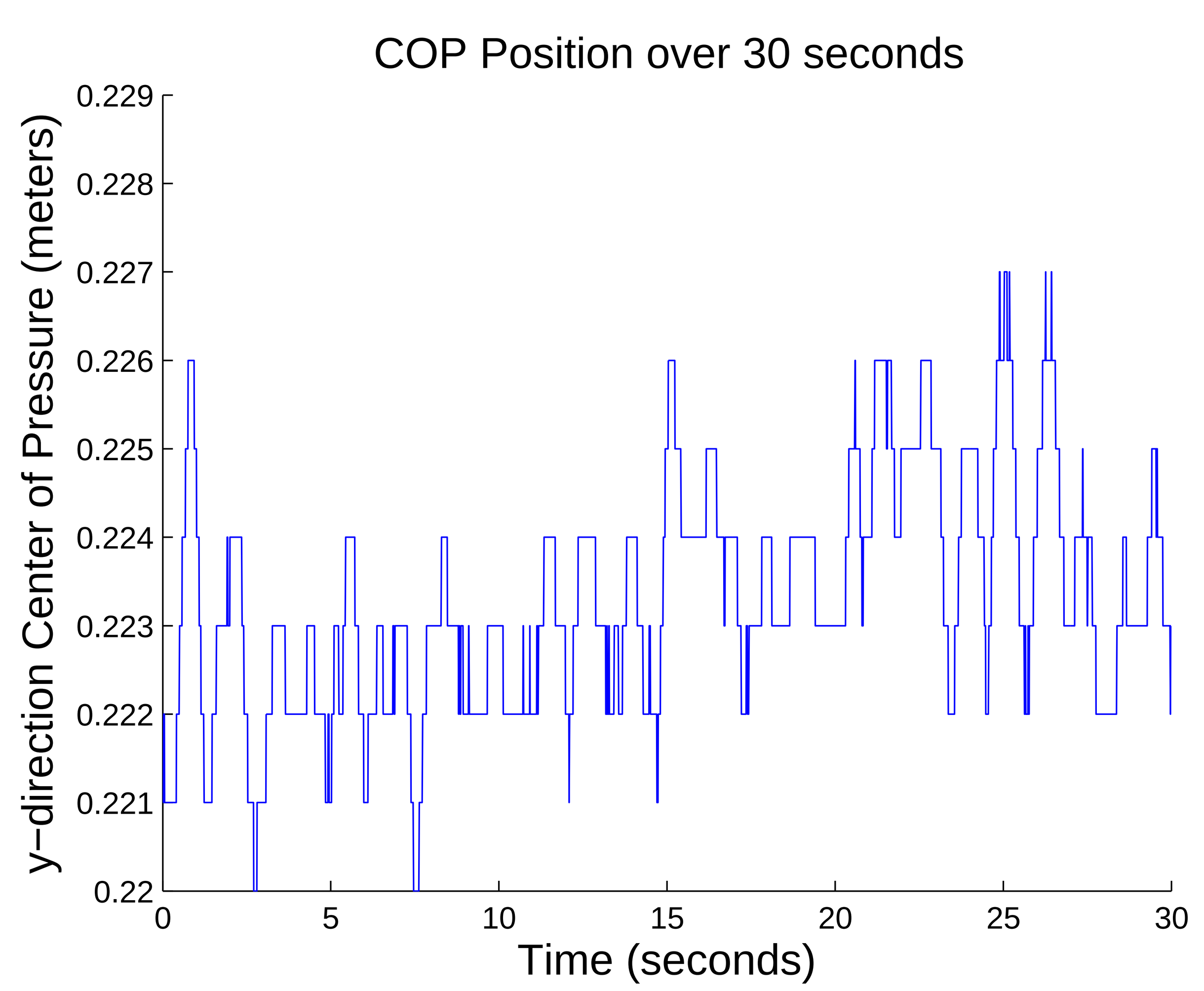


Figure 1: Seen here is the motion of the center of pressure along the y-direction for a healthy individual standing on two feet with his or her eyes open. This direction corresponds to that of looking straight ahead.

Novel Modeling Work

We created our model of the COP with the goal of producing specific qualitative features:

- Our model COP should not stray too far from a central location.
- Our model should be continuous in time.
- Like the actual COP, our model should have elements of random movement.
- Our model should be as simple as possible.

We accounted for the first two elements by using a very simple differential equation ($\frac{dX}{dt} = \gamma(\mu - X)$), and for the third element by adding a Gaussian white noise term, producing a stochastic process known as the Ornstein-Uhlenbeck Process.

Ornstein-Uhlenbeck (OU) Process

$$\frac{dX}{dt} = \gamma\left(\mu - X\right) + \sigma\xi(t)$$

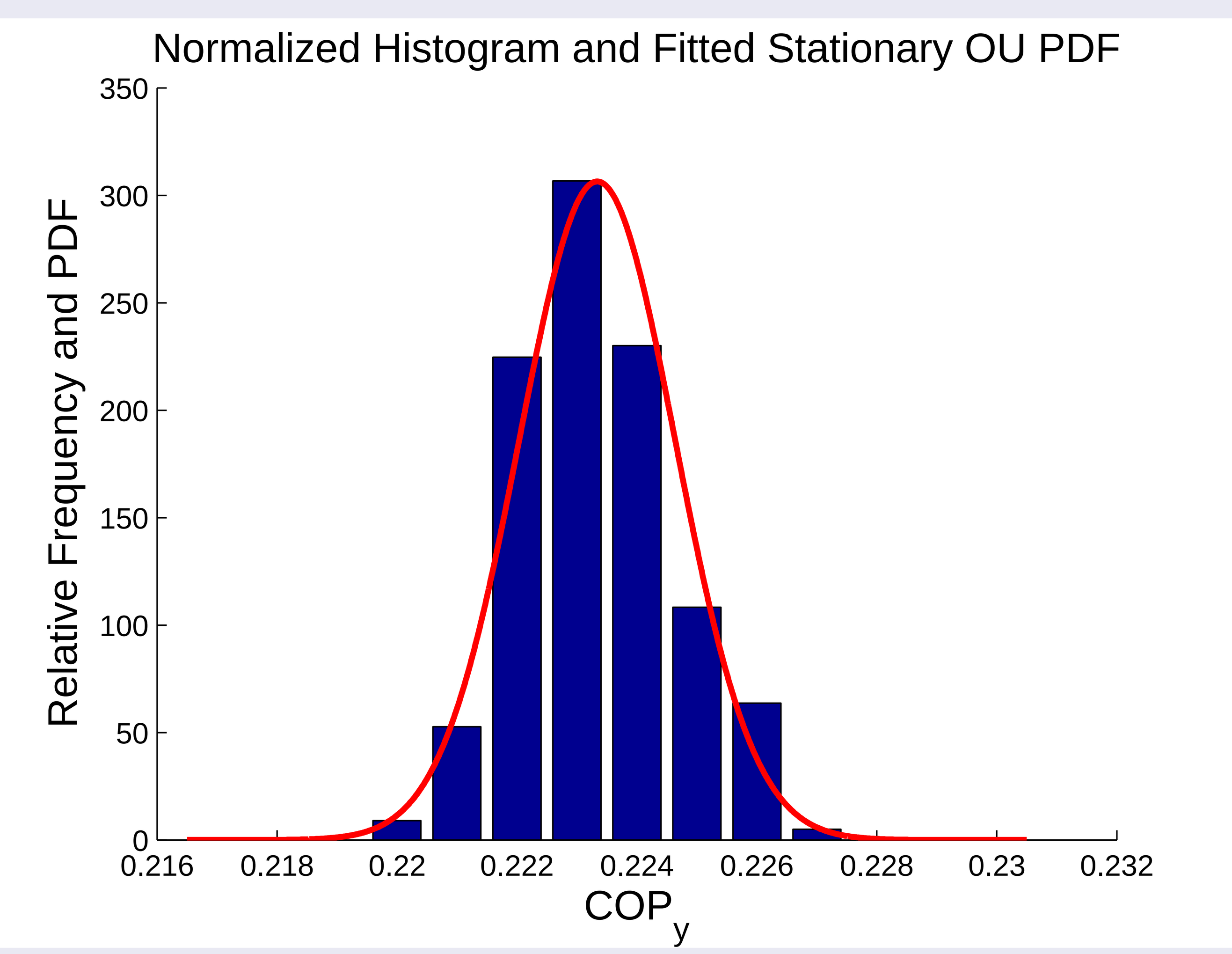
$$X(t+\Delta t) = X(t)e^{-\gamma\Delta t} + \mu\left(1 - e^{-\gamma\Delta t}\right) + \sigma\sqrt{\frac{1 - e^{-2\gamma\Delta t}}{2\gamma}}N(0,1)$$

- $X(t)$ describes the position at time t, γ is the rate of the decay towards the mean μ, and σ is the amplitude of the Gaussian white noise.
- The solution $X(t+\Delta t)$ is outlined by Gillespie in [3], but modified to add in the mean.

Comparing and Fitting the New Model with Experimental Data

We used linear regression to find the values of γ, μ, and σ that create an OU process most closely matching a given set of data. The results of this fit are shown graphically in the figure below.

Figure 2: The relative frequency of different locations for the center of pressure is shown by the blue bars. The frequency expected by the fitted OU process (the PDF) is shown in red. This is for the same particular set of data as was used in the Figure 1.



Conclusion and Ongoing Efforts

So far our work has focused on creating a new model and finding a way to use experimental data to determine the most appropriate parameters for that model. Our next step is to extensively check how well our model reproduces the qualitative and quantitative behavior of the experimental data. If the OU process is indeed a good phenomenological model, then we can move on to a more physically based model—the stochastic damped harmonic oscillator. Our future work may also help to reveal to what extent humans use an "open-loop" or "closed-loop" control system for balance, i.e. to what extent our balance control system depends on feedback.

Acknowledgments

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Notice

This project had approval from the Institutional Review Board (IRB) of the University of Northern Colorado (UNC). All participants provided their consent in accordance with policies and procedures put forth by the UNC IRB.