Optimization of Free Throw Performance

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1. Abstract
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3. Introduction
    a. Statement of the Problem
        i. Correctly performing a free throw in the game of basketball requires a complex motion by an athlete. In order to be successful free throw shooters, athletes need to perform their shooting motion in a way that can be repeated consistently many times. This project seeks to mathematically prove whether or not the accepted "perfect form" for free throw shooting is optimal way to shoot a free throw.
    b. Definition of Terms
    c. Key Results
    d. Hypothesis
        i. The most efficient motion path may be in a variety of forms but one that takes advantage of the momentum applied in the shooting direction. For instance, a "Granny-shot" could produce an optimal shot. However, the hypothesis of this study is to see if the traditional method of shooting a free throw is the most optimal when considering reliability.
    e. Scope and Limitations
        i. This study was limited to the motion of one arm performing a free throw shot. The arm was modeled as a rudimentary skeletal structure of the upper arm and forearm with muscular interaction. All arm properties were based on relative proportions based on the average height and weight of an NBA basketball player in 2015. Simplistic kinematic equations were used to derive the shooting path of the ball upon release. Constraints were enabled to prevent the simulation of joint hyperextension and muscle overloading. Optimization was performed on MatLab using a Quasi-Newton Method and a Genetic Algorithm.
    f. Significance of the Study
        i. The concept of optimizing a free throw shot can be advantageous in a variety of different sports. If an athlete can understand the physical motions required for optimal performance, he will know exactly what to practice in order to master his sport with greater motion control and consistency.

4. Methodology
    a. Concept Development - This section includes a description of how we derived our final model, including how our initial models influenced the final design.
        i. 2D model - While exploring this problem, we found which concepts would be useful by implementing more simple models. These concepts include:
            1. Explore using genetic algorithms - Overcomes local minima to find various solutions that can make a basket.
                a. Time duration of shot as input variable - We discovered that allowing our method to explore how much time a shot takes, allows for more freedom in searching for the optimal shot.
            2. Useful for applying kinematics
                a. Kinematics - Where the basketball will land
                    i. Input velocity and position, output how close to the center of the hoop
                    ii. Based on projectile motion
                    iii. Penalties are enforced if the ball isn't moving in the right direction
        ii. 3D Model of the Human Arm- The 3D model of the arm was based on bone structure and muscular proportions based on the average weight and height of an NBA player in 2015. The use of this model was to describe the optimal motion path of the arm that allowed for conservation of momentum energy.
                a. Input - Joint position for each frame
                b. Constraints - Hyperextension of joint angles and overloading of muscles due to dynamic and static torque seen in the joints.
                c. Objective - minimize the variability of the direction of the hand's velocity to capitalize on generated momentum from each stage of the free throw motion.
                d. Assumption - Based on concept that the ball should move in a straight line until it is released.
        iii. Final Model - yet to be created - Based on the the concepts we proved with our initial models we created a new model that allows us to find the optimal free throw shooting form.
            1. Use of Genetic Algorithms and Quasi-Newton Method
                a. Input variables
                    i. Time duration of shot

ii. Angles of motion path of joints

2. 3D Model of the Human Arm
3. Objective Function
    a. Most reliable way to make a free throw
4. Constraints
    a. Hyperextension of joints
    b. Overloading on muscles
5. Based on making shot - kinematics developed for 2d model
    a. Include uncertainty

b. Optimization Methodology
    i. Gradient based methods were used to explore the problem
        1. Quasi-Newton with a supplied gradient using the complex-step method
    ii. We used genetic algorithms in the end to avoid local minima problems
        1. Infinite variations of motions can make a basketball shot. We need to have motions that can make a basketball shot to study uncertainty in results
    iii. Uncertainty
        1. The goal is to find the best way to shoot a basketball. We define this as being the most repeatable, so we are searching for the most robust solution.

5. Results
    i. 2D Model
        1. GA
            a. Show preliminary results - can generate multiple shots that work. See Figure 1
        2. Kinematics works well
            a. No picture, but it works
    ii. 3D Model
        1. See Figure 2
        2. Seems to point towards a motion that is similar to current basketball shots. See Figure 3. This result was obtained by assuming that the ball should change direction as little as possible during the course of the shot. It is a promising results that gives us confidence as we begin building our final model.
    iii. Final Model - Still in progress
        1. Compare results from optimization methods
            a. GA vs Quasi-Newton
                i. Objective

ii. Active Constraints

b. Graphics

i. Visual path modification through optimization

ii. Analysis on calculated results

2. Results at different levels of reliability
3. Compare results with the traditional basketball free throw shot

6. Conclusion
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    b. Evaluate hypothesis
    c. Summary of project results
7. Discussion of the results
    a. Application to athletes
    b. Reliability vs. optimality
8. Recommendations/Future Implementation
    a. Evaluating the optimization of different sized people
    b. Branching out to other sports

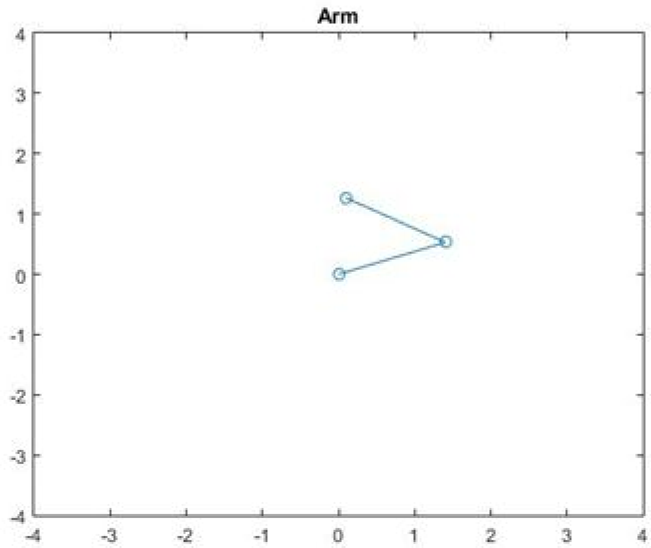

Figure 1: 2D Model - Genetic Algorithm Allows for Multiple Motions that can make a free throw

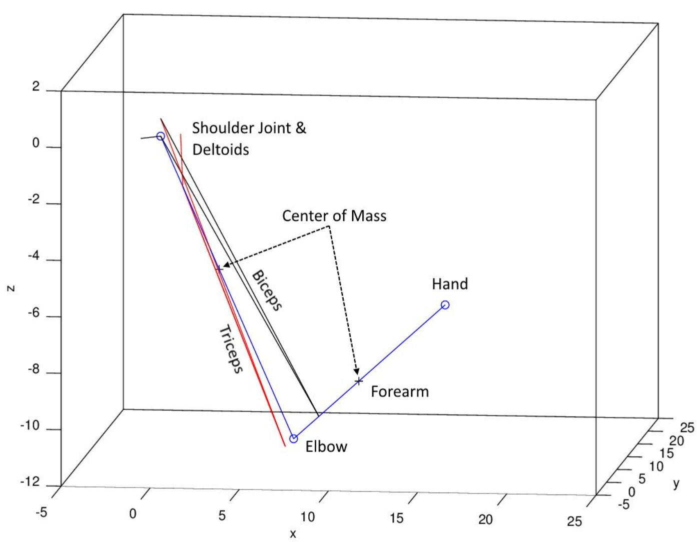

Figure 2: Depiction of 3D Model

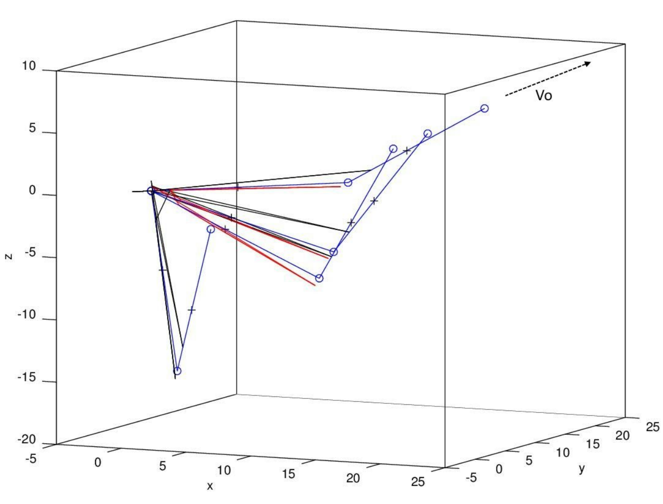

Figure 3: Preliminary result of free throw form. Final results will be generated by new model