Physical Analysis of Tango Dancing

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August 19, 2013

Abstract

This paper documents the design and construction of a system for capturing and analyzing physical data taken from subjects doing skillful activities with the use of multiple inertial measurement units. These activities have a wide range across many fields but this dataset is specifically two six degree of freedom sensors hooked up to tango dancers.

Contents

1 Introduction

1.1 Motivation

In designing a system for motion capture and data logging with human movements the industry standard is to use cameras and markers due to the relatively low cost and high effectiveness. Although this is ideal, certain activities have much of the motion obscured by a partner, teammate, or opponent thus making the use of visuals highly difficult. So with this idea in mind the use of physical data can replace visuals. Measurable observables such as linear acceleration in the $x, y, \& z$ directions and orientation in the form of Euler angles can be used to analyze and better understand the movement and thus the activity. These observables are acquired with the use of inertial measurement units and software loaded onto a microcontroller.

1.2 Goals

With a realtime data capture system one can record and analyze the data from a very good or professional dancer or athlete. When that data is analyzed, one can potentially create a real time feedback or real time correctioning system to help amateurs improve their performance by making their data signature closer to that of the professional.

2 Inertial Measurement Units

When attempting to take physical data, sensors such as accelerometers, gyroscopes, and magnetometers can be used. An inertial measurement unit (IMU) is a combination of these sensors and is used to measure and report observables such as acceleration, velocity, orientation, and force.

2.1 Degrees of Freedom

IMUs are categorized by the type and number of sensors they have. In this case six degree of free IMUs were used. This was due to the fact that each IMU contained an accelerometer and a gyroscope. Thus measuring linearly in $x, y, \& z$ as well as rotationally around each axis, providing six ways the IMU can record movement, or six degrees of freedom.

2.2 Accelerometer

Accelerometers are electromechanical devices that measure linear acceleration forces. They can be used to measure any acceleration in the $x, y, \& z$ direction and in this case that was used to aid in recognizing the direction of the movement of a dancer's leg.

2.3 Gyroscope

Gyroscopes are devices that measure orientation. In this case Euler angles were used for orientation purposes and allowed for an understanding of the legs angle change.

3 Sensor Design

3.1 Essentials

There are three main sections involved in the system: acquisition, processing, and transmission. It was concluded that the system would need to be largely wireless as well as very small and light to remain wearable and easy to move in for proper data capture.

3.2 Initial Design

The original design for the system consisted of 8 IMUs wired to a central microcontroller, an Arduino Uno R3, with the use of a multiplexer to avoid any sensors attempting to "talk over" one and other. The data processed by the Arduino would then be relayed to a computer via Bluetooth where the data would finally be logged. Ultimately, this design proved relatively successful but not entirely ideal due to the presence of wiring between each IMU and the Arduino as well as issues with data consistency as the distance on the I^2C line increased.

3.3 Second Design

The next design attempted to correct for all of the issues unaccounted for in the original. This was accomplished by instead of having one main microcontroller processing the data from all the sensors, instead each sensor would have its own microcontroller and Bluetooth module to transmit the data individually. This made the system immensely easier to wear and move in as well as allowed for more reliable data due to the lack of wires and interconnected, moving parts. Each of these individual sensory units would be housed on a velcro athletic strap ideal for wearing and moving around.

3.4 Components

3.4.1 Arduino Pro Mini Microcontroller

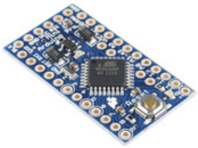

Figure 1: Arduino Pro Mini

The Arduino Pro Mini is the processing unit for each sensor. The Arduino platform is widely used for many hobby projects and prototyping because its universal design and vast online support. The Arduino Pro Mini is a small, slightly less user friendly version of the standard Arduino Uno ideal for customizable applications. The Pro Mini consists of the ATmega328 microcontroller and has an operating voltage of 3.3V. It has 14 digital I/O pins, 6 analog input pins, and a clock speed of 8MHz.

3.4.2 IMU - ITG3200/ADXL345

Figure 2: IMU - ITG3200/ADXL345

The sensor chosen for the system was a 6-DOF IMU consisting of an ITG3200 gyroscope and an ADXL345 accelerometer. The IMU runs on 3.3V and transmits the data to the Arduino via I^2C interface.

3.4.3 Bluetooth Mate

Figure 3: Bluetooth Mate Silver

For wireless transmission of data the Bluetooth Mate was chosen for speed purposes primarily. Bluetooth is capable of sending data extremely quickly and thus can eliminate any latency issues when sending data a high frame rate.

3.4.4 Polymer Lithium Ion Battery - 1000mAh

Figure 4: Polymer Lithium Ion Battery - 1000mAh

Originally a standard 9V battery was used but ultimately eliminated due to it's size and weight. So as a substitute the much smaller and lighter Polymer Lithium battery was chosen.

3.5 Implementation - Pins and and Connections

Several small wired connections were necessary on each sensory unit. Each of the IMUs requires 4 connections: data (SDA), clock (SCL), power (3.3V), and ground (GND). As for the Bluetooth, each requires four as well: write (TX), receive (RX), power (VCC), and ground (GND). All of these connections must be made into the primary processor, in this case the Arduino Pro Mini. The following diagram outlines the connections for each sensory unit.

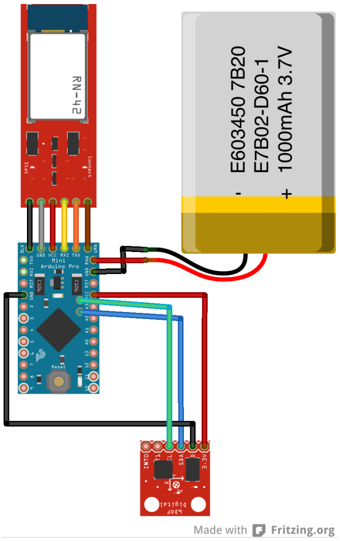

Figure 5: Connection Diagram

3.6 Cost Analysis

3.6.1 Initial Design

Component	Cost ($)	Quantity
Arduino Uno R3	29.95	1
IMU - ITG3200/ADXL345	64.95	8
Bluetooth Mate Gold	64.95	1
Analog/Digital Multiplexer	4.95	1
9V Battery	1.95	1
Total Cost	621.40	

3.6.2 Final Design

Component	Cost ($)	Quantity
Arduino Pro Mini	9.95	8
IMU - ITG3200/ADXL345	64.95	8
Bluetooth Mate Gold	64.95	2
Bluetooth Mate Silver	39.95	6
Polymer Lithium Ion Battery - 1000mAh	11.95	8
Total Cost	1064.40	
Per Sensor Cost	126.80	

4 Software

To obtain the data desired for the project, software was loaded onto each Arduino. The Arduino platform has its own programming language, based off Processing. The syntax is very close to the language C. For communication between the Arduino and IMUs to be possible both the ADXL345 and ITG3200 libraries were loaded onto the Arduino. These libraries provided the ability to initialize each IMU and get raw data.

4.1 Filtering

Over time, IMUs, particularly the gyro component, tend to drift. Drift refers to when readings tend to stray from the correct values. To compensate for this sensory drift, Sebastian Madgwick's DCM (Directional Cosine Matrix) filter was used on the raw accelerometer and gyro values.[1]

5 Measurements

5.1 Methodology

Subjects would place sensors on the back of the calf slightly toward the outside of their leg to keep contact and potential for sensory issues to a minimum. Once it was confirmed that the sensors were taking accurate data the subject would then preform a series of actions on camera. The data would then be post processed to make sure there were no unexpected spikes or unexpected Arduino resets. The data was then plotted and coupled with its corresponding video.

5.2 Observables

The sensors produce six observables: linear acceleration in $x, y, \& z$ provided by the sensor's accelerometer and Euler angles psi, theta, and phi for orientation purposes from a combination of the gyro and accelerometer. These six observables provide ample data for analysis of the motion preformed by the dancers.

5.2.1 Linear Acceleration

The acceleration values are expressed in terms of the acceleration due to gravity, $9.81 m/s^2$.

5.2.2 Orientation: Euler Angles

The sensors output three Euler angles for orientation purposes. The psi and phi values range from $-180°$ to $180°$, while the theta values range from $-90°$ to

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[1] An efficient orientation filter for inertial and inertial-magnetic sensor arrays by Sebastian O.H. Madgwick

90°. This discrepancy would be fixed in future work. Psi corresponds to a left to right pendulum motion of the leg, theta corresponds to a rotation in place, and phi corresponds to a front to back pendulum motion of the leg.

5.3 Raw Results

The following plots are of one dancer's left leg performing a series of actions. There will be a zip file containing all of the plots and videos of the subjects.

5.3.1 Walking Forward and Backward

Subject walked forward, turned, walked forward, paused, walked backward, turned, walked backward. Plots are of left leg.

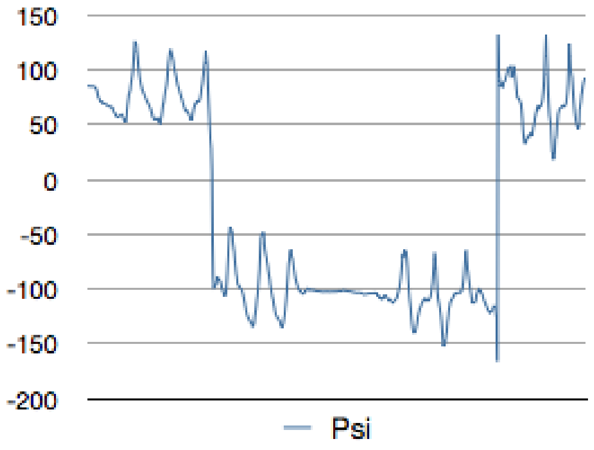

Figure 6: Psi vs. Time for Left Leg walking forward and backward

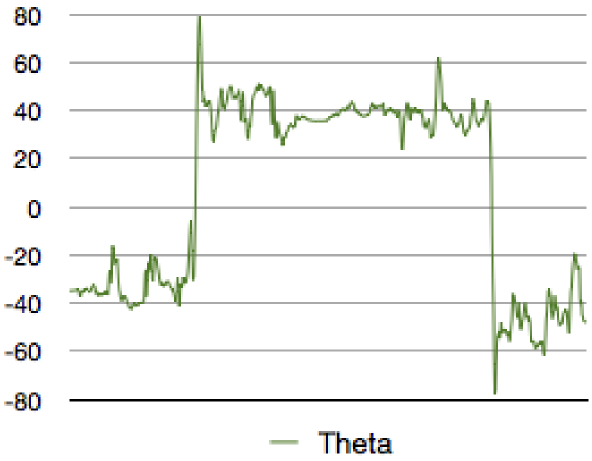

Figure 7: Theta vs. Time for Left Leg walking forward and backward

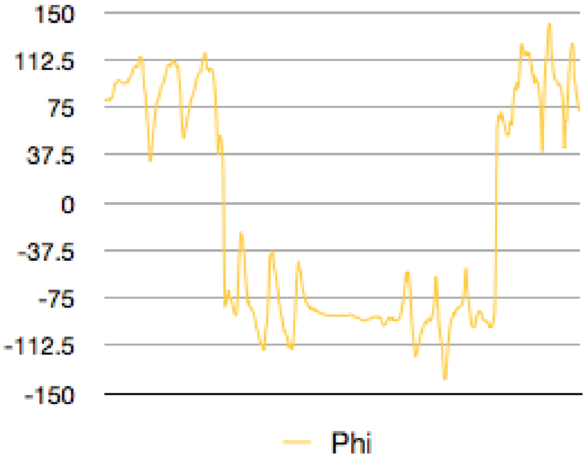

Figure 8: Phi vs. Time for Left Leg walking forward and backward

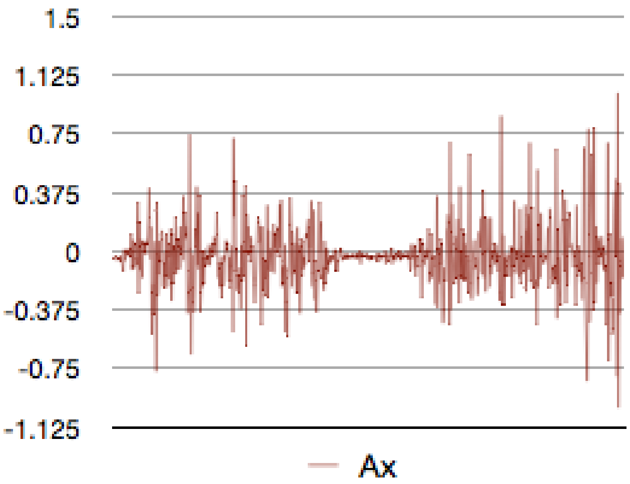

Figure 9: Acceleration in X direction vs. Time for Left Leg walking forward and backward

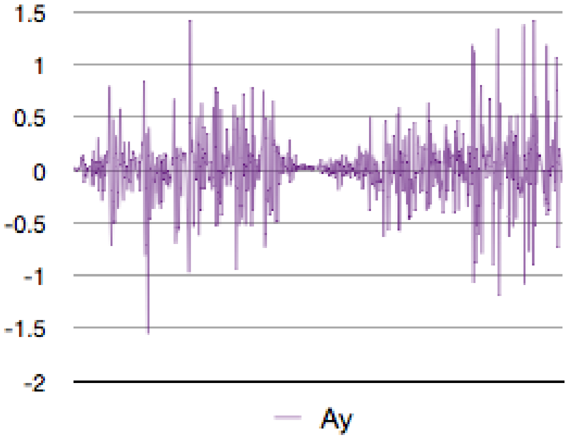

Figure 10: Acceleration in Y direction vs. Time for Left Leg walking forward and backward

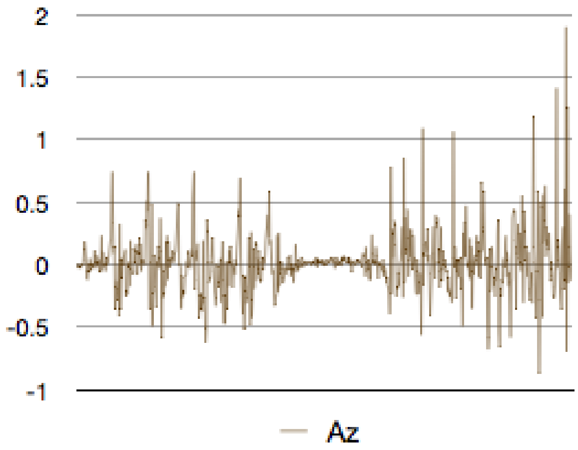

Figure 11: Acceleration in Z direction vs. Time for Left Leg walking forward and backward

Observations Walking has a relatively distinct signature, most easily recognized in the small peaks in phi. Change in direction is most easily identified by rapid change in theta. Any rest or pause will be a flat line on all observables.

5.3.2 Turning

Subject turned a total of four times alternating between anti clockwise and clockwise respectively. Plots are of left leg.

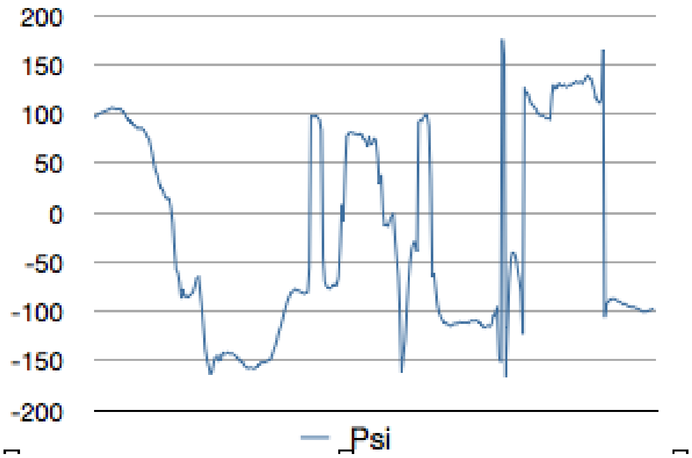

Figure 12: Psi vs. Time for Left Leg turning

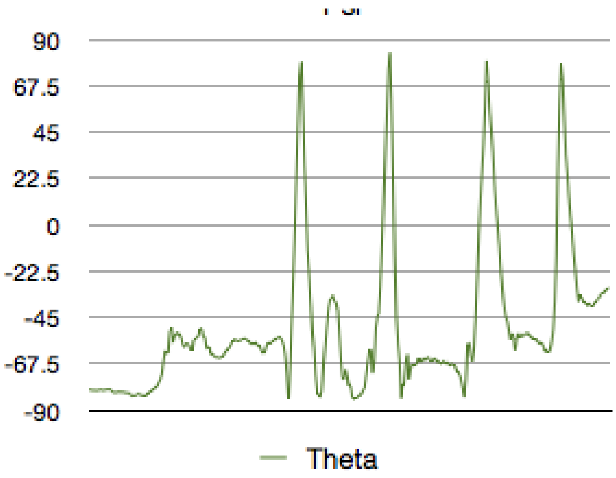

Figure 13: Theta vs. Time for Left Leg turning

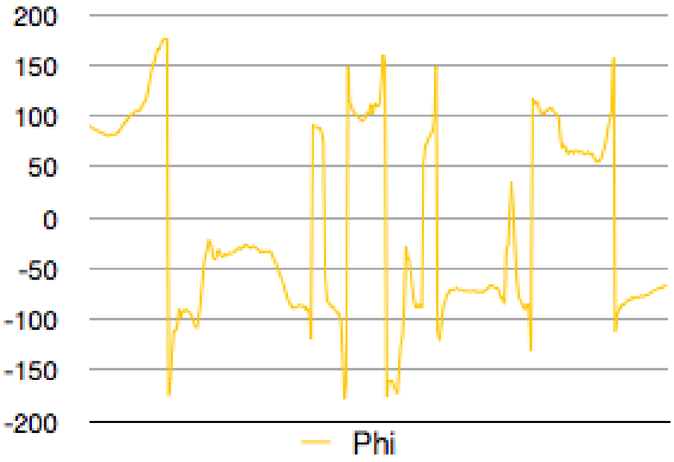

Figure 14: Phi vs. Time for Left Leg turning

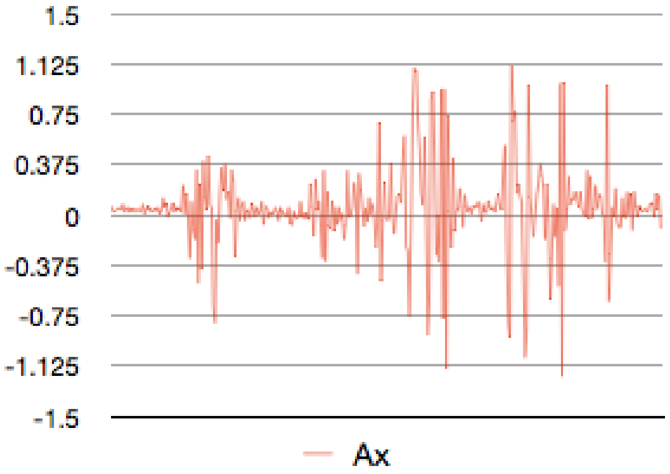

Figure 15: Acceleration in X direction vs. Time for Left Leg turning

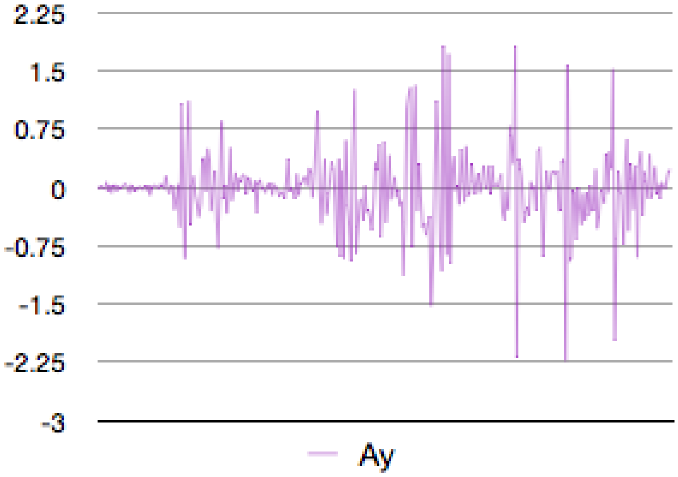

Figure 16: Acceleration in Y direction vs. Time for Left Leg turning

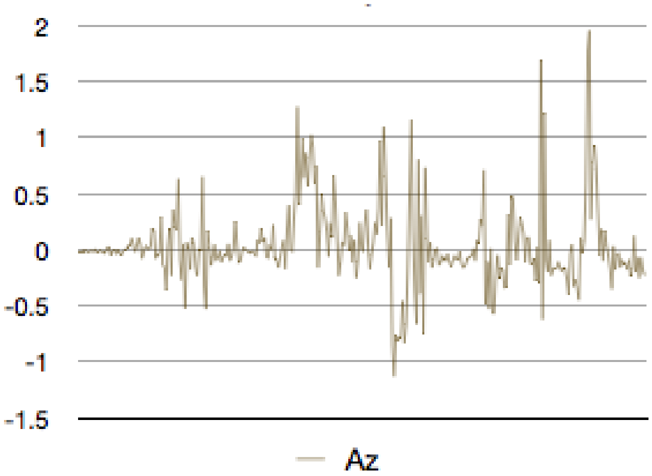

Figure 17: Acceleration in Z direction vs. Time for Left Leg turning

Observations Here the turning signature becomes more clear. Spikes in theta display each turn with the direction of the turn being identified by the sign of the first derivative at the beginning of each turn.

More Data There is much more data ready for analysis but seemed as though it would be too much to include.

6 Future Work

Ultimately although successful, accurate data was taken from dancers with two sensors there is still vast room for improvement. Having more sensors would be essential moving forward due to the intricacies and fine tuning involved in tango and other activities that could potentially be monitored. This would lead to much more post processing so ideally once enough had been learned about the motion to analyze it in real time, a feedback system could be implemented. In addition, for post processing purposes a more accurate time stamp would be necessary, ideally entirely automated. The possibilities are far ranging for the project and every improvement aides in the analysis.

7 Conclusion

This paper displayed the design and execution for a system in which physical data is captured from subjects preforming skillful activities. Successful two sensor data capture was done on tango dancers of varying ability in an attempt to gather enough raw data for analysis.

8 Acknowledgements

I would like to thank Dennis Shasha for the opportunity and help along the way. I would also like to thank all of the dancers that subjected themselves to being rigged up with sensors while they danced!