PoMS: Posture Monitoring Shirt

A comfortable shirt that uses Machine Learning to generate posture-defining coordinate transforms based on electrical resistance from stretch sensors

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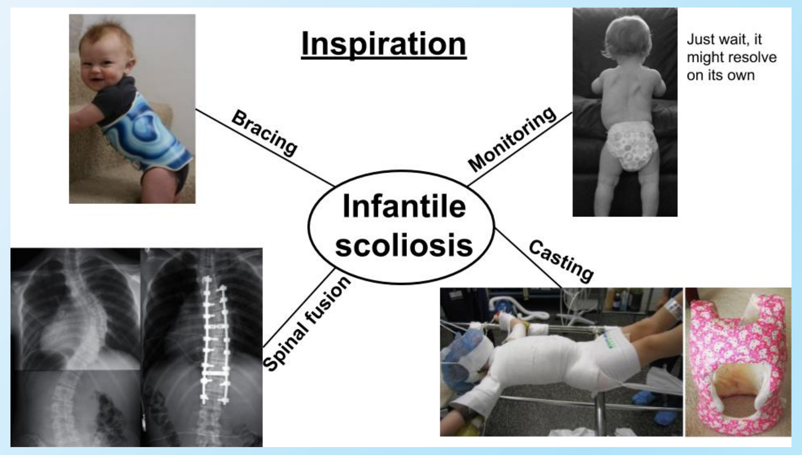
ABSTRACT

The objective of this research was to create a comfortable, highly informative, accurate posture monitoring shirt, which would not limit the wearer's natural range of motion. The Posture Monitoring Shirt (PoMS) consists of a tightly fitting garment with twelve stretch sensors whose electrical resistance changes with their length. The resistance of each sensor was recorded with an Arduino circuit. To help account for the hysteresis in the sensors, the change in resistance over time was also recorded. Posture was defined as a set of three coordinate transforms: pelvis to sternum, sternum to left shoulder, and sternum to right shoulder. An experiment was conducted to determine the accuracy of PoMS. During the experiment, the ground truth posture was recorded with a Vicon motion capture system and retroreflective markers strategically placed on appropriate anatomical landmarks. The coordinate transforms were generated with Matlab using the Vicon recorded position of the markers. Subjects (n = 5) performed six cyclic movements, using specific degrees of freedom. Afterward, they incorporated movement in all six degrees of freedom into one minute of random torso motion. Four Machine Learning (ML) regression models were created to predict the torso posture based on the resistance input data: Linear Regression, K Nearest Neighbor, Random Forest, and a Neural Network. The algorithms were trained with the single degree of freedom movements and used to predict the freestyle, random movements. The results are very promising and show that the developed methodology is successful. PoMS can be used for an extremely wide variety of medical and athletic applications. Since bad posture and back problems are very common, PoMS has potential to help everyone.

INTRODUCTION

1.1 Background

- The design of PoMS was inspired by desire to help children with infantile scoliosis. Current treatment methods for infantile scoliosis are extremely uncomfortable and standard protocol dictates that treatment should be avoided if the curvature could correct on its own.



- The creation of PoMS enables scientists to easily and accurately record body posture, making studies of various diseases, such as scoliosis, much more efficient.
- The shirt could help millions of individuals who experience back pain as a result of habitually assuming a hunched posture (Figure 1).
- PoMS can also be transformed into a biofeedback device to help wearers improve their posture in real time.

Figure 1. Rodin's *The Thinker*, exemplifies bad posture.

1.2 Literature Review

- Scientists have attempted to develop posture monitoring technology for over 75 years [1][2][3].
- All of the studies I have looked at have severe limitations, either in efficacy or accuracy, and all have a narrow range of application [4][5].
- Unfortunately, most attempted treatments have not worked and people often resort to painkillers and wait for the pain to pass [6].
- Health care expenses account for more than 17% of GDP in the United States, and back and neck problems constitute a significant portion of that [7]. In 2013, the U.S. spent $88 billion on health care expenses for lower back and neck pain [8][9].

1.3 Significance

- Monitoring body posture has the potential to accelerate discovery in many areas: medical research (ex. infantile scoliosis), sports, general public.
- PoMS can be transformed into a biofeedback system to evaluate posture on the spot and provide verbal feedback to the wearer.

1.4 Research Problem & Hypothesis

- Create a posture monitoring shirt that would be
  - Comfortable
  - Accurate
  - Highly informative
  - Inexpensive so that ultimately the product could be easily mass-produced
  - Not limit the wearer's natural range of motion
- I hypothesized that creating such a shirt using resistive stretch sensors and employing Machine Learning models to accurately predict posture is possible.

METHODOLOGY I - DESIGN

2.1 Choosing a Stretch Sensor

- Stretch sensors' electrical resistance changes with their length. However, they are not pre-calibrated and the exact relationship is not known
- This preliminary study was designed to
  - determine if the length of the stretch sensor used in the shirt could be accurately determined by its electrical resistance
  - which of the two types of sensors being considered was more reliable.
- I recorded the electrical resistance and actual length at 20ms intervals with an Arduino and two slide potentiometers while changing the length.
- Analyzing the relationship between them allowed me to determine which sensor was most reliable.
- Testing revealed hysteresis. To cope with it I also used the change in resistance over the last 20ms ($\Delta R/\Delta t$).

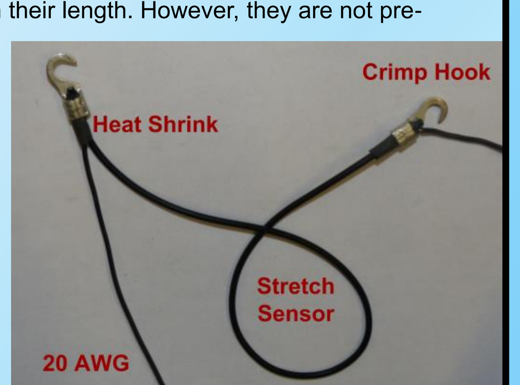


Figure 2. Stretch sensor attached to the hook crimps and insulated from them with heat shrink.

2.2 Creating the Shirt

- PoMS was created from
  - Commercially available tightly-fitting, comfortable compression shirt
  - 15mm buttons which I sewed onto the shirt to correspond with notable anatomical landmarks (Figure 4).
  - Stretch sensors assembled with the crimp hooks and heat shrink (Figure 2).
- During my experiments the resistance of each sensor was recorded at regular time intervals with an Arduino circuit (Figure 3) consisting of 12 voltage dividers.

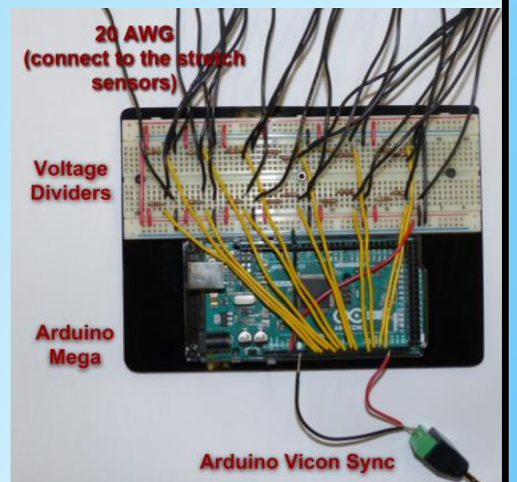


Figure 3. Voltage divider circuit used to record the resistance of the stretch sensors during the experiment.

METHODOLOGY II - DEFINING POSTURE

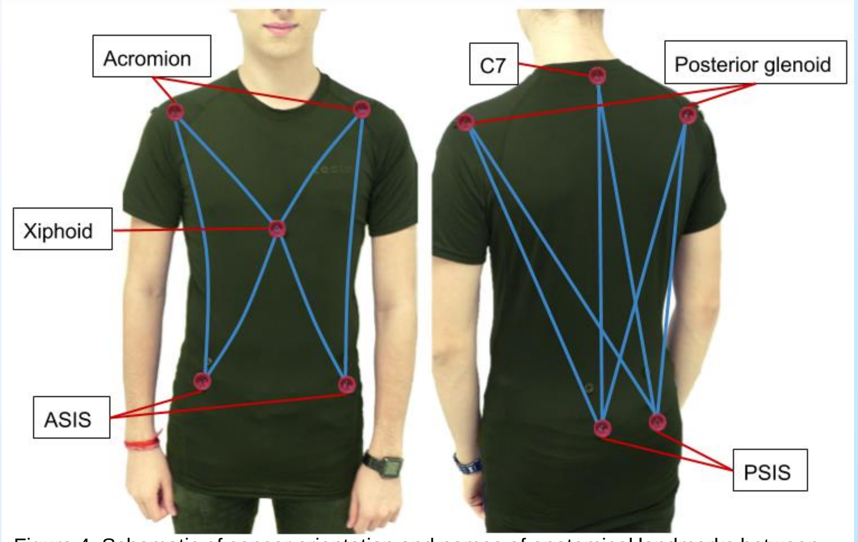


Figure 4. Schematic of sensor orientation and names of anatomical landmarks between which they were attached.

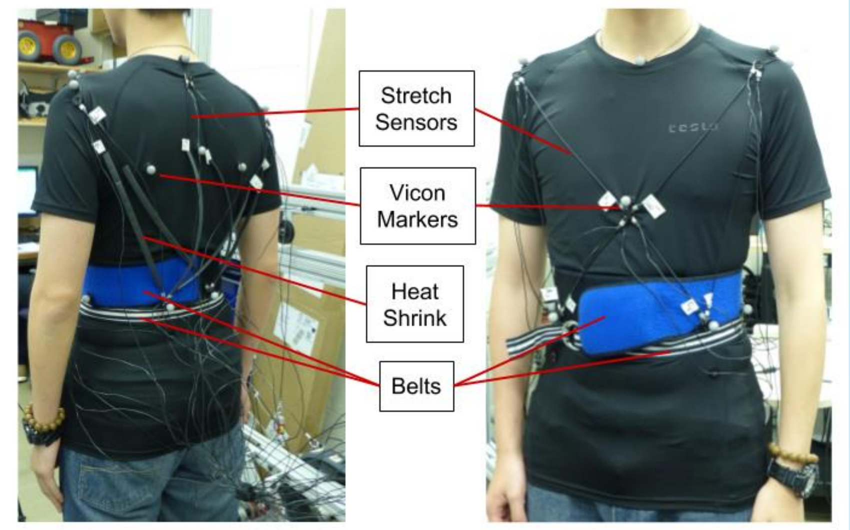


Figure 5. Picture of completed PoMS from experiment. The belts were used to prevent the shirt from sliding.

2.3 Defining Posture Mathematically

- To comprehensively define torso and shoulder posture I used three coordinate transforms between the major segments of the torso (Pelvis, Sternum, Left Shoulder, and Right Shoulder) defined as follows:

Pelvis coordinate system
Origin: PSIS center

$$\mathrm{PSIS\_center} = \frac{\mathrm{Right\_PSIS} + \mathrm{Left\_PSIS}}{2}$$

$$\mathbf{x\text{-}axis} = \frac{(\mathbf{Right\_ASIS} - \mathbf{Left\_ASIS})}{||(\mathbf{Right\_ASIS} - \mathbf{Left\_ASIS})||}$$

$$\mathbf{z\text{-}axis} = \frac{(\mathbf{Right\_ASIS} - \mathbf{PSIS\_center}) \times (\mathbf{Left\_ASIS} - \mathbf{PSIS\_center})}{||(\mathbf{Right\_ASIS} - \mathbf{PSIS\_center}) \times (\mathbf{Left\_ASIS} - \mathbf{PSIS\_center})||}$$

$$\mathbf{y\text{-}axis} = \mathbf{z\text{-}axis} \times \mathbf{x\text{-}axis}$$

Figure 6. Representation of the four coordinate frames used to represent the torso.

Sternum coordinate system
Origin: C7

$$\mathrm{C7\_SternalNotch\_center} = \frac{\mathrm{C7} + \mathrm{SternalNotch}}{2}$$

$$\mathrm{xiphoid\_T8\_center} = \frac{\mathrm{xiphoid} + \mathrm{T8}}{2}$$

$$\mathbf{z\text{-}axis} = \frac{\mathbf{C7\_SternalNotch\_center} - \mathbf{xiphoid\_T8\_center}}{||\mathbf{C7\_SternalNotch\_center} - \mathbf{xiphoid\_T8\_center}||}$$

$$\mathbf{x\text{-}axis} = \frac{(\mathbf{xiphoid\_T8\_center} - \mathbf{C7}) \times (\mathbf{SternalNotch} - \mathbf{C7})}{||(\mathbf{xiphoid\_T8\_center} - \mathbf{C7}) \times \mathbf{SternalNotch} - (\mathbf{C7})||}$$

$$\mathbf{y\text{-}axis} = \mathbf{z\text{-}axis} \times \mathbf{x\text{-}axis}$$

Shoulder (left and right) coordinate system
Origin: respective acromion

$$\mathbf{x\text{-}axis} = \frac{\mathbf{posterior\_glenoid} - \mathbf{acromion}}{||\mathbf{posterior\_glenoid} - \mathbf{acromion}||}$$

$$\mathbf{y\text{-}axis} = \frac{\mathbf{x\text{-}axis} \times \mathbf{inferior\_scapular\_angle} - \mathbf{acromion}}{||\mathbf{x\text{-}axis} \times \mathbf{inferior\_scapular\_angle} - \mathbf{acromion}||}$$

$$\mathbf{z\text{-}axis} = \mathbf{x\text{-}axis} \times \mathbf{y\text{-}axis}$$

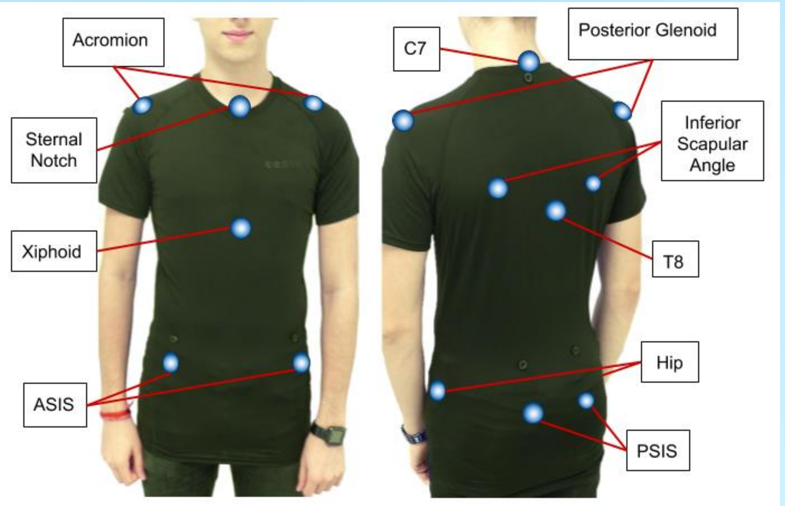


Figure 7. Position of Vicon retroreflective markers.

After establishing these four coordinate frames, transforms between them were generated.

- To do this, four transform matrices were created.
- Here is the transform matrix for the pelvis (P represents the pelvis, the superscript represents the pelvis axis, the subscript represents the component of that axis from the perspective of the Vicon/world frame, and "o" stands for origin):

$$\begin{bmatrix} P_x^x & P_x^y & P_x^z & P_x^o \\ P_y^x & P_y^y & P_y^z & P_y^o \\ P_z^x & P_z^y & P_z^z & P_z^o \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- Let P represent the pelvis transformation matrix and S represent the sternum transformation matrix. The coordinate transform was generated by $[P]^{-1}[S]$. The same was repeated for the other transforms.
- As a result, 18 parameters were generated. Each transform included translations, in the x, y, and z directions, and rotations, pitch (about the x-axis), roll (about the y-axis), and yaw (about the z-axis).

RESULTS

Sternum-Left Shoulder Transform

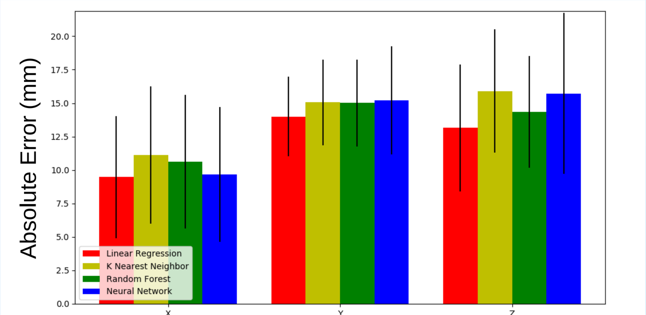


Figure 8. Average absolute error (in mm) as predicted by ML algorithms for the translations in the sternum-left shoulder coordinate transform.

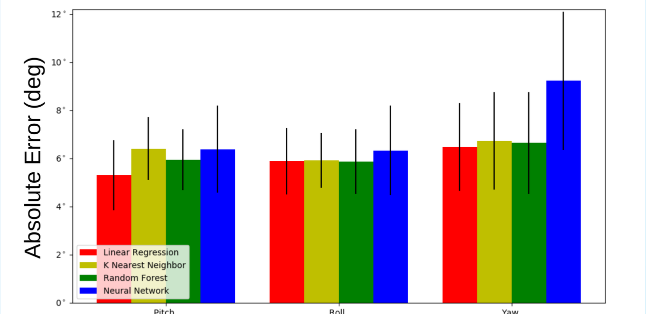


Figure 9. Average absolute error (in deg) as predicted by ML algorithms for the rotation in the sternum-left shoulder coordinate transform.

Sternum-Right Shoulder Transform

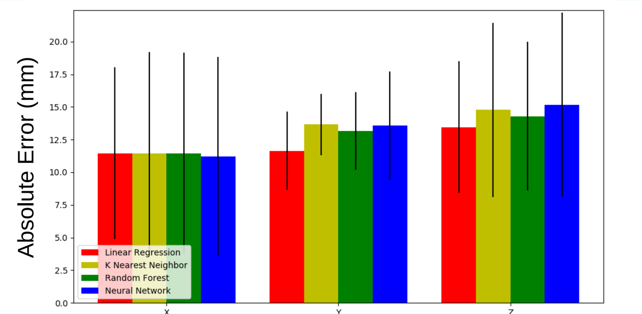


Figure 10. Average absolute error (in mm) for the translations in the sternum-right shoulder coordinate transform.

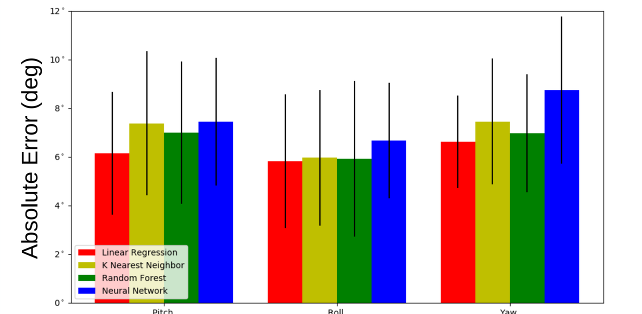


Figure 11. Average absolute error (in deg) for the rotation in the sternum-right shoulder coordinate transform.

Pelvis-Sternum Transform

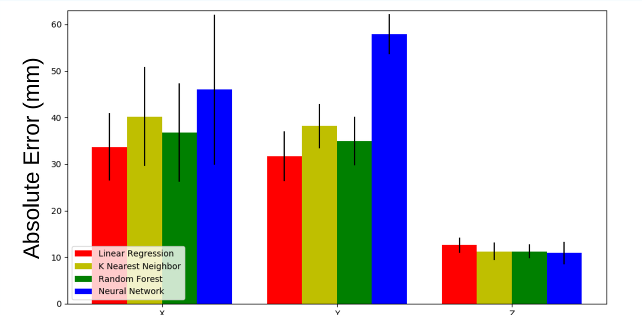


Figure 12. Average absolute error (in mm) for the translations in the pelvis-sternum coordinate transform.

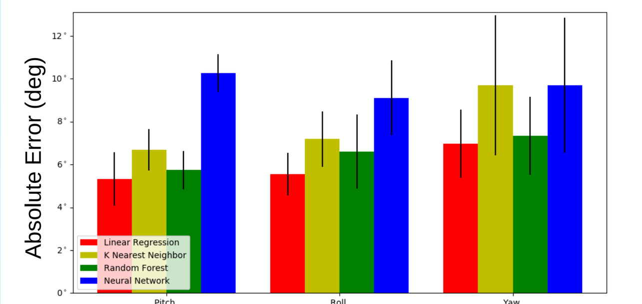


Figure 13. Average absolute error (in deg) for the rotation in the pelvis-sternum coordinate transform.

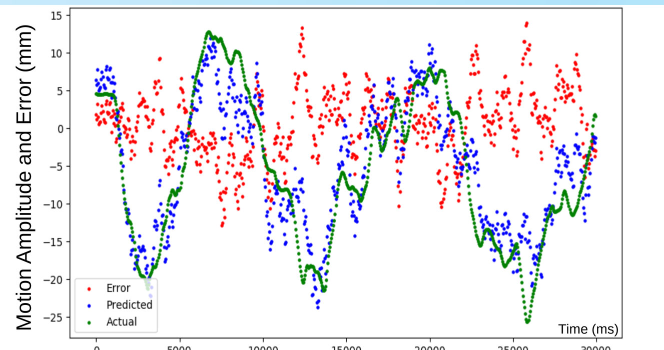


Figure 14. Prediction of the Z translation with Linear Regression (pelvis-sternum transform, subject one, freestyle A).

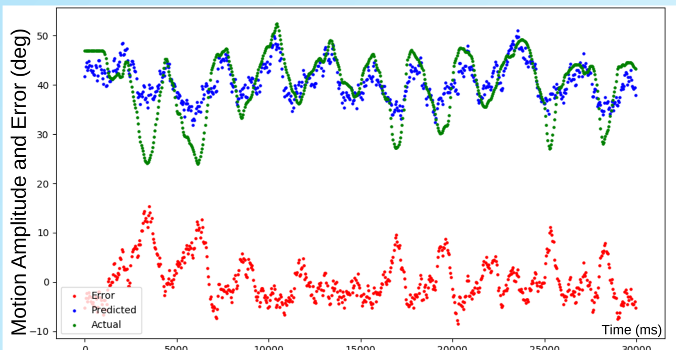
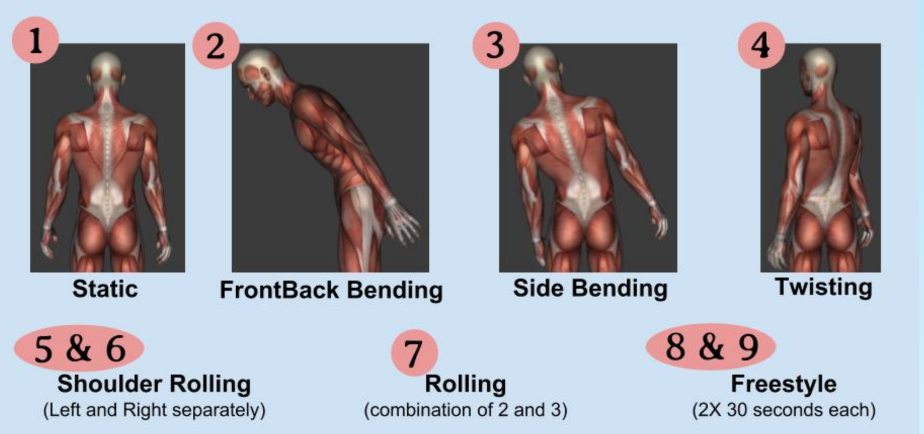


Figure 15. Prediction of pitch with Linear Regression (pelvis-sternum transform, subject one, freestyle A).

METHODOLOGY III - PROCEDURES

2.4 Procedure

- The experiment consisted of nine sections: seven isolated, cyclic movements and two freestyle, random movements.
- The movements were timed with a metronome for uniformity. First two iterations: 8 sec. Second two iterations: 4 sec. Last two iterations: as fast as they could.



- I had five subjects.

2.5 Training Machine Learning Algorithms

- I used Matlab and Python to preprocess and filter the Vicon data and electrical resistance data from the sensors.
- I used the data from the isolated movements to train four regression ML models using Scikit-Learn [13]: Linear Regression, K Nearest Neighbor, Random Forest, and a Neural Network.
- I used Vicon recorded coordinate transforms (torso movements) as ground truth and used resistance data as the observation to predict transforms.
- Absolute error between the predicted and actual transforms served as my parameter of success.
- I tested the models on the freestyle, random portion of the experiment.

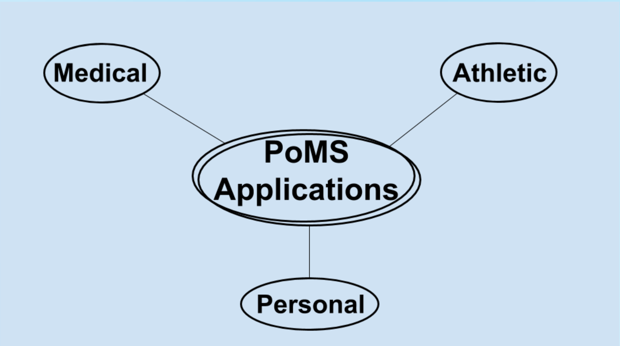
DISCUSSION

4.1 Interpretation of Results

- The linear model was the most accurate. Imperfections in predictions were caused by noise and hysteresis but the other three algorithms were not better at accounting for them.
- PoMS does a particularly good job with all the angles, with the average absolute error falling below 6.3 degrees on average.
- The predictions were slightly less accurate for the translations, with most of them having an average absolute error in the low teens (below 13.2 mm).
- PoMS was better at predicting lower amplitude movements (Figure 15) which means that it would be even more accurate in applications that don't involve bending to capacity.

4.2 Summary of Discovery

- Ultimately, I created a shirt that was capable of predicting the wearer's posture over time with relatively high accuracy.
- In addition to the relative position of the pelvis and sternum, PoMS was able to predict the relative position of the shoulders. This makes it the most informative posture monitoring device in existence, capable of predicting eighteen degrees of freedom twenty times per second.
- PoMS is comfortable and versatile, accommodating the wearer's entire natural range of motion.
- The shirt was designed for a wide variety of applications. While the shirt was only tested for accuracy, it is widely applicable in many areas.



4.3 Limitations and Future Research

- With its current sensor configuration, PoMS can predict angles with much greater accuracy than some translations. However, many applications don't require all 18 degrees of freedom and different sensor orientations can be implemented to accommodate each use.
- There can be an infinite number of sensor configurations and they could be used in various parts of the body, depending on the application.
- My methodology can be developed further to create a wireless, biofeedback wearable system which evaluates the posture in real time and provides verbal feedback to the wearer, for example, through a phone application.
- AI algorithm can be developed, allowing PoMS to become more "intelligent" as it collects more data and provide more reliable and relevant feedback with time.

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