University of Waterloo
Faculty of Engineering

Design and Analysis of a System to Classify Occurrence of Pressure Relieving Exercises in Wheelchairs

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Dr. Paul Fieguth, Professor and Chair,
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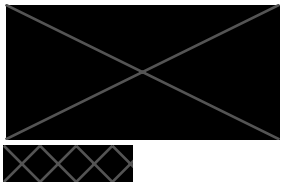
Dear Professor Fieguth,

I have prepared this report "Design and Analysis of a System to Classify Occurrence of Pressure Relieving Exercises in Wheelchairs" as my 4B Work Report as an extension of the work my team is doing for our fourth year design project. This report is the fourth and final report that I must submit as part of my degree requirements, and it has not received any previous academic credit.

This report contains previous design work which are from a collaboration with my team members Deep Jani, Priya Menon, and Karthiga Vezhavendan. We collaborated on the background research, electrical schematic, and design of the pressure mat. The design team is interested in reducing the occurrence of pressure injuries in at-risk elderly wheelchair users in long-term care facilities.

I would like to thank my team members for their support on the project.

Valentin Tsatskin



Abstract

Studies have found that pressure injuries, also known as pressure ulcers or bedsores, affect up to 58% of all wheelchair users [1]. The constant pressure against the patient's body can result in injuries to the skin and underlying tissue. To reduce the occurrence of pressure injuries, wheelchair users are recommended to perform pressure relieving exercises (PRE).

A system is being developed by the author's fourth year design project (FYDP) team which encourages wheelchair users to perform PREs regularly. An Internet of things (IoT) pressure sensing mat is used to collect sensor readings of various PRE and non-PRE exercises. A system is proposed to classify if a time series of pressure readings is a PRE. The system's classification precision and recall is analysed and a suitable classifier and feature space is chosen. Recommendations for further improvement of the classification are discussed.

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Background

1.1 Problem of Concern

Studies have found that pressure injuries, also known as pressure ulcers or bedsores, affect up to 58% of all wheelchair users [1]. The constant pressure against the patient's body can result in injuries to the skin and underlying tissue and thus are called pressure injuries. Not only are they painful, pressure injuries can also worsen the condition of patients and can be expensive to treat, primarily because of the additional support required of clinicians. Although weight-shifting exercises (also known as pressure relieving exercises, PRE) help prevent pressure injuries, research has shown that patients do not maintain these healthy behaviors perhaps because of a lack of incentives [2].

A system is being developed by the author's fourth year design project (FYDP) team which encourages wheelchair users to perform PREs regularly. An Internet of things (IoT) pressure sensing mat is currently being designed, prototyped, and tested to collect data for clinicians to track effectiveness of PREs and understand risk factors for wheelchair users in long-term care communities.

1.2 Pressure Relieving Exercises

According to the literature, there are four main exercises used to relieve pressure acting on the ischial tuberosities, the sacrum and lower back: side-to-side shifting, leaning forward, chair push ups (also known as chair dips) and tilting or reclining the wheelchair [3]. These four exercises are specifically tied to pressure relief, and are recommended for individuals who are at risk for developing pressure injuries.

1.3 System Overview

An overview of the system developed as part of the FYDP team in shown in Figure 1. For the purposes of this report, the wheelchair user, pressure mat, Raspberry Pi software, and server are relevant components of the system.

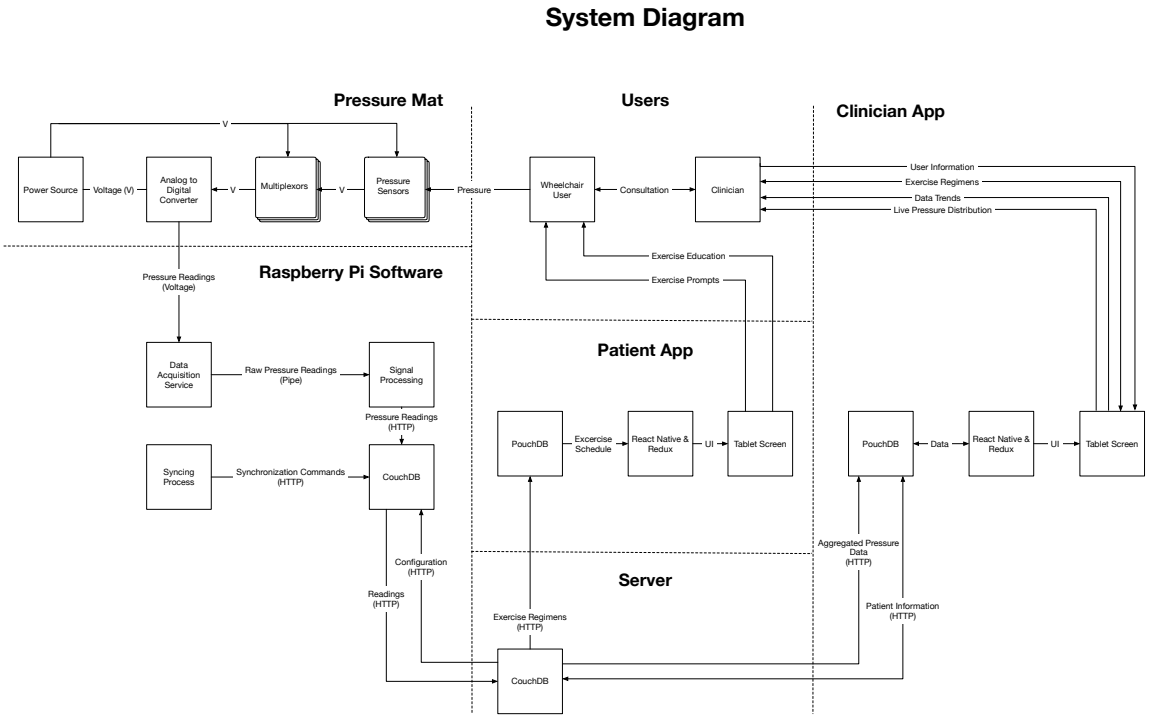


Figure 1: System Diagram

1.4 Pressure Mat

An electrical schematic of the pressure mat system is shown in Figure 2. An array of 34 SEN-09375 Force Sensitive Resistors were used to record pressure readings [4]. The physical layout of the sensor readings are shown in Figure 3. A Raspberry Pi running Raspberian was used to collect analog readings from the sensors. The sensors were connected to three CD74HC4067SM96 Multiplexers [5] which were connected to an MCP3008 analog-to-digital converter (ADC) [6]. The Raspberry Pi controlled the ADC and multiplexers, recorded the sensor readings, and synchronised the data to CouchDB compatible cloud database.

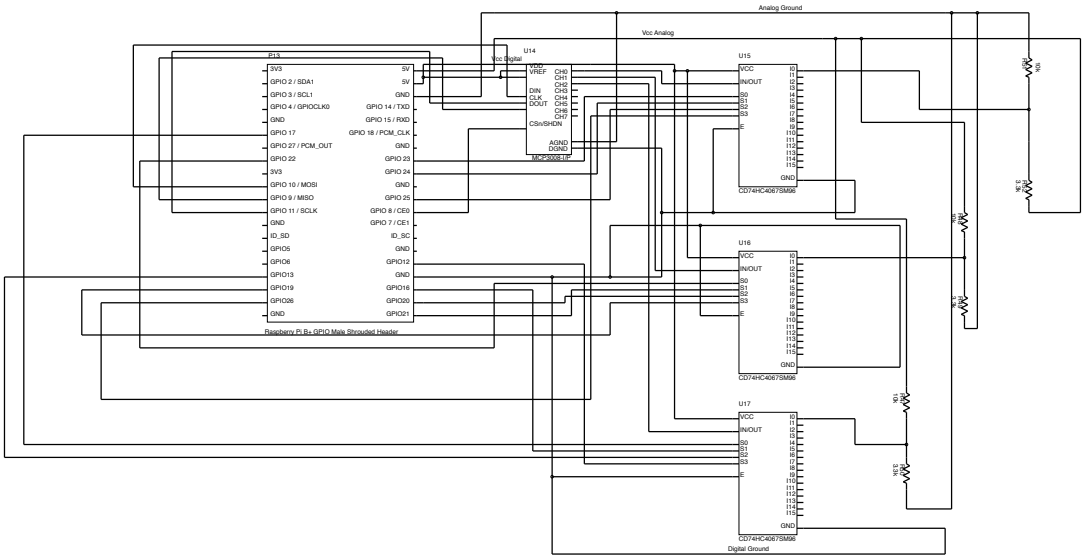


Figure 2: Electrical schematic of pressure mat

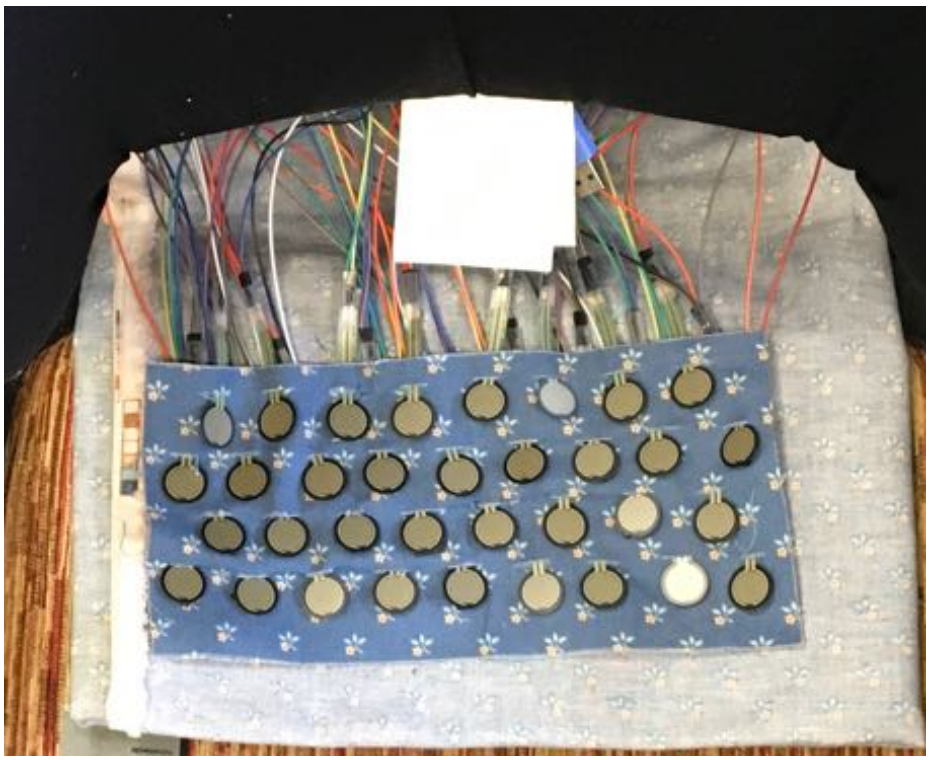


Figure 3: Picture of prototype pressure mat

2

Design and Analysis

Classification of time series pressure sensors readings to determine if a wheelchair user is performing a PRE is an important sub-system for the FYDP. A system for differentiating between between PRE and sitting poses is proposed, shown in Figure 4. Two classifiers, logistic regression and support vector machines (SVM) are proposed as classifiers. Three different features are proposed for collapsing a time series of N sensor readings into a feature vector of length N: mean, standard deviation, and variance. The precision and recall of each combination of classifier and feature is evaluated. The minimum number of observations while ensuring acceptable performance is determined.

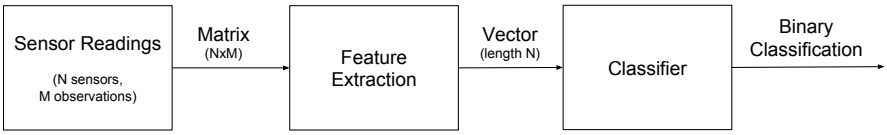


Figure 4: Classification System Diagram

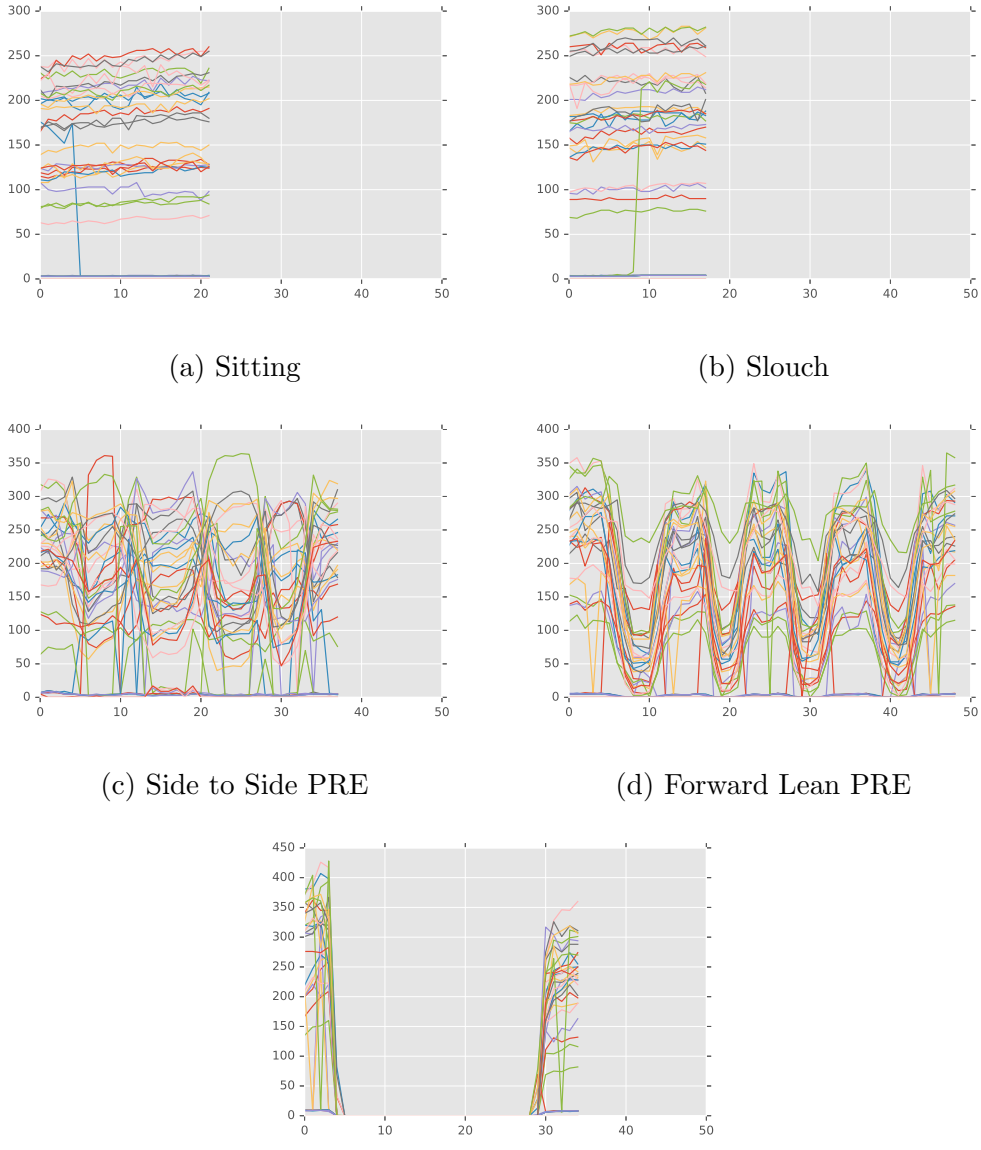
2.1 Data Collection

Pressure mat readings were collected for one participant performing various poses. The participant was a 23 year old male weighing approximately 140 lbs. Two sitting poses were were collected: sitting with an upright posture with their back in contact with the chair and sitting with a slouched posture. Three pressure relieving poses were collected: leaning side-to-side to focus pressure on each buttock; leading forward to distribute pressure to the lower thigh; and chair dips. Each pose was collected multiple times with the participant standing up from the wheelchair and sitting down again to slightly change the location of where the pressure sensors were located on the body. A table summarising the number of recordings can be found in Table 1. Observations

of pressure readings from 34 sensors were collected at a rate of 2.7 Hz.

2.2 Data Exploration

To understand what features of the data to use, the data needed to be visualised and explored. Samples of the sensor recordings for each pose are shown in Figure 5. The following observations were made:



(a) Sitting

(b) Slouch

(c) Side to Side PRE

(d) Forward Lean PRE

(e) Dip PRE

Figure 5: Time series samples of each pose performed.

- Non-PRE poses are relatively constant signals compared to PRE. Thus it is hypothesized that PRE have a higher variance of sensor readings than non-PRE poses.
- Some sensors have issues where they sporadically connect/disconnect.
- All sensor readings from forward lean movement is reduced when transferring pressure to lower thigh which is not measured by pressure mat.

2.3 Proposed Features and Classifiers

From the PRE variance hypothesis, it was proposed that variance and standard deviation of each sensor reading over the entire session were used. Thus all of the data in a session was reduced to vector with length equal to the number of sensors in the system. As an experiment, the mean of each of the sensor readings over time was used as well. Logistic regression and SVM were chosen as proposed classifiers.

Table 1: Statistical summary of number of observations in each session grouped by pose

Pose	**Session Count**	**Min**	**Median**	**Max**
Sitting	5	17	21	25
Slouch	5	17	18	20
Side to Side PRE	5	32	38	40
Forward Lean PRE	5	32	42	50
Dip PRE	6	18	20	35
Total	**26**	**17**	**23.5**	**50**

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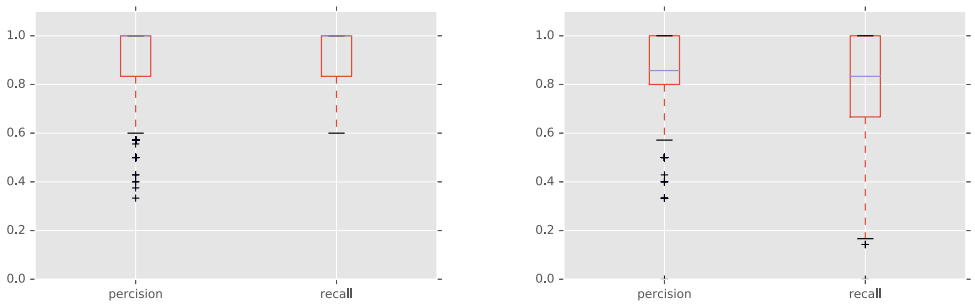
Results

To understand how well each proposed classifier and proposed features were performing on the PRE classification task, a quantitative measure of performance was used. Precision and recall were used as the metrics to evaluate classification performance. Each classifier and feature pair were evaluated using a random test/train split of $\frac{1}{3}$ and $\frac{2}{3}$ respectively. To understand the typical performance of a classifier and feature pair on unseen data, a test/train split was performed 1000 times and a statistical summary of the experiments was recorded in Figures 6 and 7.

Comparing the two classifiers across all features, it is clear logistic regression performs better with regards to precision than SVM due to having higher median precision. However, SVM performs better in recall across all features. Logistic regression with mean sensor values as a feature has the best performance in precision results across both classifiers and all features. The recall performance is the best across all features in logistic regression, but does not perform better than any SVM results. However, due to the median precision and recall scores being both 1.0, with no other pair having similar results, this classifier/feature pair appears to perform the best.

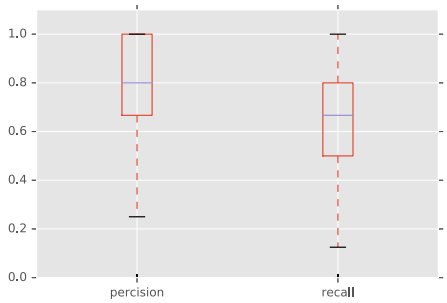
Performing a dimensionality reduction to 2 dimensions using PCA upon the data before classifying with logistic regression yields plots shown in Figure 8. Standard deviation with PCA performs best as a feature in both precision and recall across all features regardless of usage of PCA.

To understand the minimum number sensor observations needed to attain the aforementioned performance of using standard deviation with PCA as a feature space and logistic regression as a classifier, the same experiments as before were run while varying the number of samples. From the plot shown in Figure 9, a minimum of 9 observations is required for acceptable performance. From the data rate of 2.7Hz, this means 3.33s of data is required to identify if a PRE is being performed.



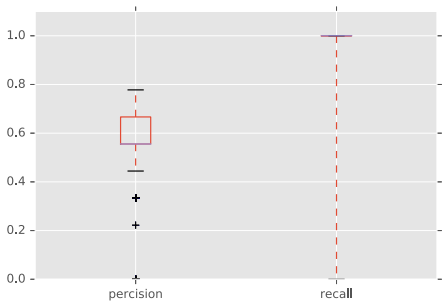
(a) Mean

(b) Standard Deviation

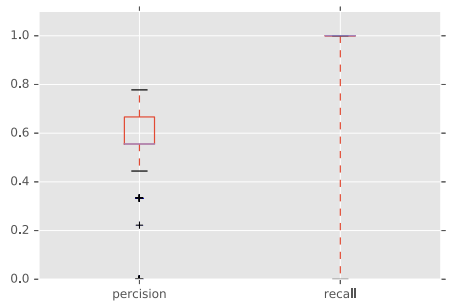


(c) Variance

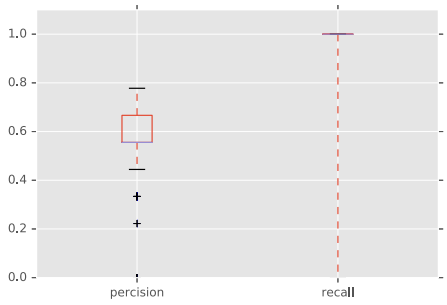
Figure 6: Classification performance of logistic regression classifier on proposed features with a random test-train split run 1000 times. 33% of data withheld for testing.



(a) Mean

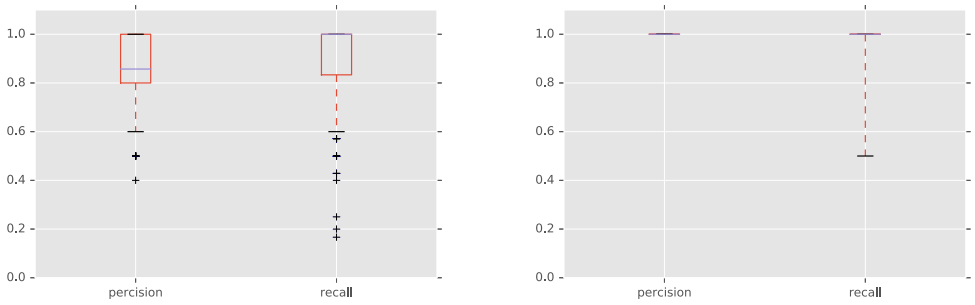


(b) Standard Deviation



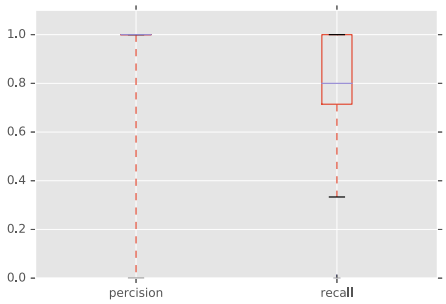
(c) Variance

Figure 7: Classification performance of SVM classifier on proposed features with a random test/train split run 1000 times. 33% of data withheld for testing.



(a) Mean

(b) Standard Deviation



(c) Variance

Figure 8: Classification performance of logistic regression classifier on proposed features with PCA dimensionality reduction onto 2 dimensions.

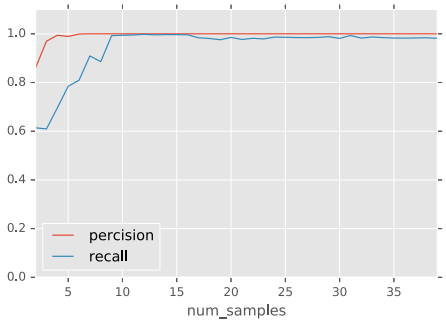


Figure 9: Mean classification precision and accuracy of 1000 test/train splits using standard deviation, PCA, and logistic regression.

4

Discussion

Due to the data collection consisting of one participant, more data from other participants is needed to understand how this classification system will perform with varying body types, sizes, and ages. The target demographic of elderly people are notably absent from this data collection. Thus, data will need to be collected from people with body and mobility characteristics similar to that of the intended system's users.

The system was not tested in terms of its real-time classification capabilities. Thus its performance characteristics are not currently known. In addition, it is not known how well the classification precision will perform in real scenarios with large amounts of data being collected throughout an entire day.

Performing PCA may be costly step in the process due to having to perform singular value decomposition (SVD). If this step is to be used, Randomised Truncated SVD will need to be performed due to it performing many times faster than full SVD [7].

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Recommendations

From the results observed, it is recommended that logistic regression be used as a classifier for the PRE classifier system. Standard deviation of sensor values should be used a feature if PCA is feasible to use within the system. If PCA is not available, mean sensor values should be used a feature instead.

More data should be collected from a variety of body types, sizes, sexes, and ages. The analysis in this report should be repeated when this data is available.

At this time, it is not known what the minimum number of sensors as well as their configuration are required in order to classify PRE accurately. It is possible that there is an abundance of sensors due to the ability of the classification system to perform classification exceptionally well with only 2 dimensions. Thus, the design team should perform an analysis to determine a design for a minimum number of sensors after more data is collected.

From the data exploration phase, it is evident that some sensors connect/disconnect sporadically. An investigation should be performed to find the root cause of this issue.

6

Conclusions

From the work outlined in this report, the feasibility of classifying PREs from a time series of pressure readings is certain. Although more data from varied participants is required to understand the robustness of the proposed design, the work in this report has laid the ground work for further refinement of the system.

Performing logistic regression on the standard deviation of time series sensor readings after dimensionality reduction using PCA yields excellent results in precision and recall (1.0 median results for both metrics). Using this method, 3.33 seconds of data captured is required to identify if a PRE is being performed.

7

Citations

References

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