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An Investigation to Improve Classifier Accuracy for Myo Collected Data

by Michael H Lee, Andre V Harrison, and Robert P Winkler

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14. ABSTRACT
A naïve Bayes classifier trained with 1,360 samples from 17 volunteers performs at an accuracy of 72.5% (based on 10-fold cross validation). This accuracy is based on using the entire data set. One approach to increasing the accuracy is by analyzing the data and removing irregular samples from the training set. As the quality of the training data increases, the accuracy of the classifier will increase. This report describes analysis of 2 features of the training data, observed unusual patterns, and how fine tuning the training set increased the accuracy by 7.2%.

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1. Introduction

The Battlefield Information Processing Branch of the Computational and Information Sciences Directorate has been investigating methods to detect, perceive, and understand human behavior and actions through wearable and environment sensors and other Internet of Things devices. One of the research projects in this area has been using the Myo wearable sensor to classify different North Atlantic Treaty Organization (NATO) hand gestures. As part of this project, a pilot study was conducted to record a small sample of the NATO hand gestures using the Myo armband from a group of individuals.[1] From this data set of gestures, several preexisting machine learning classifiers were tested (e.g., naïve Bayes [NB], logistic model tree [LMT], k-nearest neighbor [IBK]) and evaluated based on their classification performance on the data.[2] From the data, subject-specific and generic gesture classification models were developed for each classifier. The subject-specific models had extremely high performance 99% accuracy; however, the generic models had a much lower performance; the best models could not achieve an F-score of 90%.[2]

To find insight into ways to improve the classifier accuracy on the gesture data, the data analysis tool, R, was applied to the data collected by the Myo. By plotting the sensor waveforms output by the Myo, it was very quickly observed that some of the data recorded were invalid. By removing these invalid data samples, accuracy of most classifiers was improved. In the following sections, the pilot study used to create the gesture data set is described in a bit more detail. The procedure under which the gesture data were examined, evaluated, and determined to be valid or invalid is described. Then, the results of using the cleaned-up gesture data set to train several classifiers are compared to the results of using the full data set for each classifier.

2. NATO Gesture Myo Dataset

On July 2015, the US Army Research Laboratory collected NATO gesture movement data from 17 volunteers. Each volunteer performed 8 gestures (Freeze, Rally Point, Hurry Up, Down, Come, Stop, Line Abreast Formation, and Vehicle) 10 times, generating a total of 1,360 recorded motion gestures. The movement parameters from each iteration were recorded in plain-text format. Details of the data collect procedure was documented in ARL-TN-0699, *Hand Gesture Data Collection Procedure Using a Myo Armband for Machine Learning*.[1] Table 1 lists the 16 features recorded by the Myo during the data collect. Movement was captured at 10 Hz, and the data were saved as comma-separated values.

Table 1 16 features of a gesture movement

Gesture feature
Roll
Pitch
Yaw
xGyro/sec
yGyro/sec
zGyro/sec
xAccel_g (xAcc)
yAccel_g
zAccel_g
xAccelWorld_g
yAccelWorld_g
zAccelWorld_g
X-Direction
xOrientationWorld
yOrientationWorld
zOrientationWorld

3. Plotting using the R Tool

The statistical analysis tool called R was used to analyze the gesture data. A line chart was plotted for each gesture's feature (e.g., Pitch, xAcc) per user. All 10 recorded samples of a particular gesture for a single volunteer were plotted on the same chart for quick comparison. For example, the chart illustrated in Fig. 1 was generated with the following input conditions:

Gesture:	Come
Volunteer:	01
Feature:	Pitch
Samples:	01–10

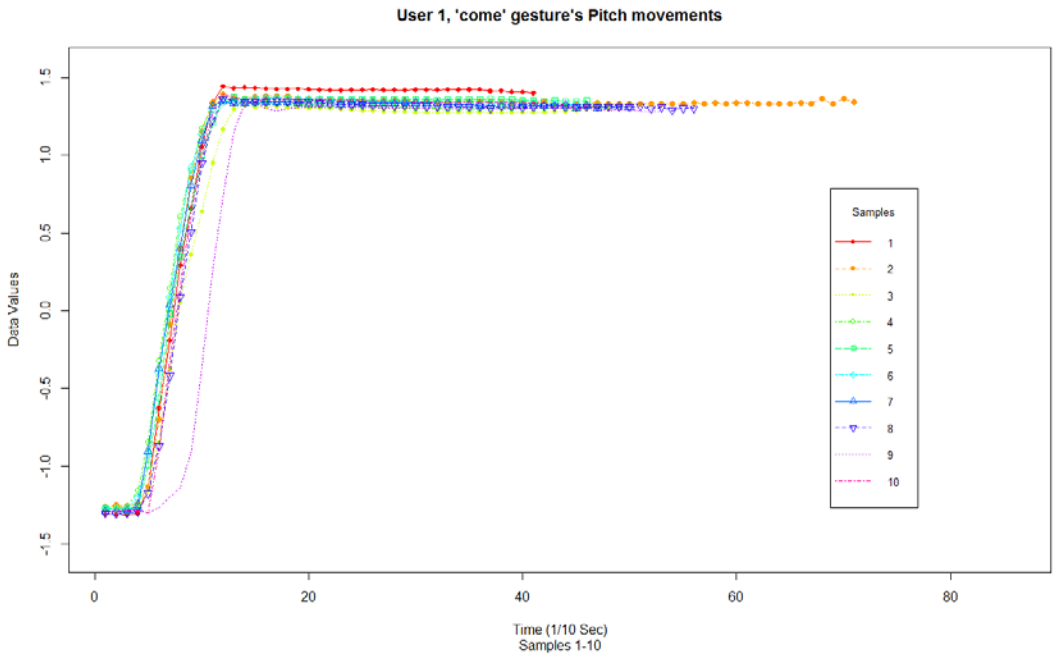

Fig. 1 Plot of user 01, Come gesture, pitch feature, samples 01–10

Each of the samples drawn on the chart is distinguished by color, shape of the marker, and style of the line. The first sample is indicated by red solid line with solid red circle. The second sample is indicated by orange dashed line with solid orange circle. These attributes help quickly identify a particular line plotted on a grouped chart.

The x-axis represents time in 1/10-s increment. For example, Fig. 1 shows that the second sample (indicated by orange) lasted approximately 7 s. The y-axis represents the value of the particular feature. For example, Fig. 1 shows that the second sample started with a pitch value of approximately –1.3 and increased to a pitch value of approximately 1.3. Charts were configured to use the same x- and y-axis range for a given gesture's feature. In other words, all of the Come gesture's pitch charts were plotted using the same x- and y-axis range. Having the same dimension resolution allowed us to compare data without adjusting the scale for each view.

Out of the 16 features, only 3 features (pitch, yaw, and xAcc) were analyzed, due to time constraints. The pitch feature records the up and down motion, the yaw feature records the side-to-side motion, and xAcc records the acceleration values along the x-axis. Pitch and yaw features were selected due to the ease in understanding how the gesture should look on a waveform. This makes it easier to track the motion of the gesture in 2 dimensions and detect abnormalities in the up/down and side/side movements. Roll was briefly analyzed, but early on it was

observed that there were little observable differences in the data, so no further analysis of the roll feature was done. The xAcc feature was selected because it was identified as the most influential feature out of the 16 features (Table 2).

Table 2 Ranking of classification importance of local features captured by the Myo

Ranking	Attribute
1.4113	xAcc
1.1772	zAccel_g
1.0188	Pitch
0.9179	zGyro/sec
0.653	yGyro/sec
0.6359	xGyro/sec
0.297	Pose
0.2344	yAccel_g
0.2324	Roll
0.176	Yaw

During the analysis of the 3 features, it was decided not to remove any samples based on unusual yaw movements. In the context of the NATO gestures chosen for this data collect, it was generally acceptable for a subject to perform a gesture with variations in the yaw movement. For example, during a Come gesture, it was acceptable if the subject raised a hand in a subtle clockwise motion or a counter-clockwise motion.

4. Analysis

Each generated chart was manually reviewed for unusual behavior. Samples that moved in unexpected fashion were tallied as shown in Tables 3 and 4 (the full data plots are provided in Appendixes A and B, respectively). Table 3 is a record of samples that had a problematic pitch value movement for a given gesture. Table 4 is a record of samples that had a problematic xAcc value movement for a given gesture. Empty cells indicate samples moved within an expected way. A summary of the categorized samples per user and per gesture is listed in Tables 5 and 6, respectively.

Table 3 Tally of unusual samples respect to pitch

User	Come	Down	Freeze	Hurry up	Line abreast formation	Rally point	Stop	Vehicle
01	…	…	…	…	…	…	…	…
02	…	1	10	5	…	10	…	…
03	…	…	…	…	…	…	…	…
04	…	…	…	…	…	…	…	…
05								
06	10	10	10	10	10	10	10	10
07	…	…	…	…	…	…	…	…
08	…	…	…	…	…	…	…	…
09	…	…	…	…	…	…	…	…
10	…	…	…	2	…	…	…	…
11	…	1	…	…	…	…	…	…
12	…	…	…	…	…	…	…	…
13								2
14	10	10	10	10	10	10	10	10
15	…	1	…	…	…	1	…	…
16	10	10	10	10	10	10	10	10
17	…	…	…	…	…	…	…	…

Table 4 Tally of unusual samples respect to xAcc

User	Come	Down	Freeze	Hurry up	Line abreast formation	Rally point	Stop	Vehicle
01	…	…	…	…	…	…	…	…
02	…	…	2	…	…	1	…	…
03	…	…	…	…	…	…	…	…
04	10	10	10	10	9	10	10	…
05	…	…	…	…	…	…	…	…
06	…	…	…	…	…	…	…	…
07	…	…	…	…	…	…	…	…
08	…	…	…	…	…	…	…	…
09	…	…	…	…	…	…	…	…
10	…	…	…	…	…	…	…	…
11	…	1	…	…	…	…	…	…
12	…	…	…	…	…	…	…	…
13	…	…	…	…	…	…	…	2
14	…	…	…	…	…	…	…	…
15	…	…	…	…	…	1	…	…
16	…	…	…	…	…	…	…	…
17	…	…	…	…	…	…	…	…

Table 5 Summary of categorized samples per user

User	Samples with conforming movements	Samples with unusual movements
01	80	0
02	54	26 (32.50%)
03	80	0
04	11	69 (86.25%)
05	80	0
06	0	80 (100%)
07	80	0
08	80	0
09	80	0
10	78	02 (2.50%)
11	79	01 (1.25%)
12	80	0
13	78	02 (2.50%)
14	0	80 (100%)
15	78	02 (2.50%)
16	0	80 (100%)
17	80	0
Total	1,018	342 (25.15%)

Table 6 Summary of categorized samples per gesture

Gesture	Samples with conforming movements	Samples with unusual movements
Come	130	40 (23.53%)
Down	127	43 (25.29%)
Freeze	120	50 (29.41%)
Hurry up	123	47 (27.65%)
Line abreast formation	131	39 (22.94%)
Rally point	119	51 (30.00%)
Stop	130	40 (23.53%)
Vehicle	138	32 (18.82%)
Total	1,018	342 (25.15%)

Most of the observed abnormalities were caused by a reversed chart movement compared to the majority of the samples from the same category. Normally, a user performs the Come gesture by raising an open hand from the side hip up to shoulder. A correct pitch movement should be a chart that starts low and sharply rises, mirroring a sharply rising hand. Users with a reversed movement showed charts with movement from high position and sharply dropping; 100% of the gesture data from users 06, 14, and 16 exhibited a reversed pitch feature movement and 86.25% of the gesture data from user 04 exhibited a reversed xAcc feature movement.

In most cases, cells with 10 indicate that all 10 samples exhibited a reversed pattern instead of sporadic sudden jumps or dips. Most users with reversed movement demonstrated consistent reverse movement throughout all 8 gestures. It is unclear why some user samples have these reversed movements. It would be reasonable to

assume that these reversed motions may have been caused by wearing the Myo armband in reverse. However, wearing the armband sensor backward would not affect the pitch in an inverse manner.

Minimal correlation was observed between unusual movements in the pitch feature and the xAcc feature. Users with many pitch movement irregularities had very few (if any) xAcc movement irregularities. For user 06, 100% of the samples were marked irregular due to its pitch feature; however, user 06's xAcc data moved in the same direction as the other xAcc samples. The same pattern is observed with users 14 and 16. From the xAcc perspective, 86.25% of user 04's samples were marked irregular due to its xAcc feature; however, no irregularities were found in user 04's pitch data.

Excluding the described reversed movements, there were only 13 (<1%) samples with abnormal pitch feature and 7 (<1%) samples with abnormal xAcc feature. Abnormalities in the xAcc group includes isolated increases or decreases in the beginning or at the end of the gesture movement.

5. Removal of Bad Samples Effect on Classification Accuracy

Once the 1,360 samples in the NATO gesture data set were analyzed and unusual samples were identified, they were removed from the training set. The remaining 1,018 approved samples were used to test and train a NB, LMT, and IBK classifier using a machine learning software called Weka.[3] (Usage of the machine learning utility and generating the classifier is out of scope of this report). An ensemble classifier that combines the output of the LMT, IBK, and NB classifiers was also trained using this cleaned-up data set.

5.1 Naïve Bayes (NB) Classifier Accuracy

The NB classifier was compared against the same classifier trained with the entire 1,360 data set. Using the 10-fold cross validation approach, the NB model trained with 1,360 samples scored 72.5% accuracy, while the NB trained with 1,018 samples scored 7.7554 percentage points higher at 80.2554%.

What follows are the statistics generated from the NB classifier trained on the 1,360 sample and tested using 10-fold cross validation:

```
=== Summary ===
Correctly Classified Instances         986               72.5    %
Incorrectly Classified Instances       374               27.5    %
Kappa statistic                          0.6857
Mean absolute error                      0.0835
Root mean squared error                  0.2177
Relative absolute error                 38.1939 %
Root relative squared error             65.8201 %
Coverage of cases (0.95 level)          95.2206 %
Mean rel. region size (0.95 level)      26.0478 %
Total Number of Instances             1360

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.535    0.067    0.532      0.535    0.534
0.467    0.900     0.530     freeze
                 0.865    0.018    0.875      0.865    0.870
0.851    0.978     0.926     rally_point
                 0.429    0.048    0.562      0.429    0.487
0.429    0.906     0.571     hurry_up
                 0.941    0.005    0.964      0.941    0.952
0.946    0.998     0.988     down
                 0.735    0.048    0.687      0.735    0.710
0.668    0.958     0.780     come
                 0.641    0.033    0.736      0.641    0.686
0.646    0.965     0.806     stop
                 0.765    0.044    0.714      0.765    0.739
0.700    0.972     0.813     line_abreast_formation
                 0.888    0.052    0.709      0.888    0.789
0.761    0.979     0.877     vehicle
Weighted Avg. 0.725    0.039    0.722      0.725    0.721
0.684    0.957     0.787

=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
  91  10  27   0  12   0   0  30 |   a = freeze
   4 147   3   0   8   0   0   8 |   b = rally_point
  36   8  73   0  33   0   0  20 |   c = hurry_up
   9   0   1 160   0   0   0   0 |   d = down
  24   0  17   0 125   0   0   4 |   e = come
   0   1   2   6   0 109  52   0 |   f = stop
   0   0   1   0   0  39 130   0 |   g = line_abreast_formation
   7   2   6   0   4   0   0 151 |   h = vehicle
```

The following are the statistics generated from the NB classifier trained on the vetted 1,018 sample and tested using 10-fold cross validation:

```
=== Summary ===
Correctly Classified Instances         817               80.2554
%
Incorrectly Classified Instances       201               19.7446
%
Kappa statistic                          0.7742
Mean absolute error                      0.0579
Root mean squared error                  0.1966
Relative absolute error                 26.4897 %
Root relative squared error             59.4592 %
Coverage of cases (0.95 level)          93.3202 %
Mean rel. region size (0.95 level)      19.3762 %
Total Number of Instances             1018

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.742    0.042    0.701      0.742    0.721
0.682    0.965     0.710     freeze
                 0.630    0.012    0.872      0.630    0.732
0.714    0.983     0.892     rally_point
                 0.886    0.035    0.779      0.886    0.829
0.806    0.984     0.938     hurry_up
                 0.937    0.007    0.952      0.937    0.944
0.937    0.999     0.991     down
                 0.785    0.037    0.756      0.785    0.770
0.736    0.973     0.824     come
                 0.677    0.021    0.822      0.677    0.743
0.713    0.966     0.808     stop
                 0.847    0.046    0.730      0.847    0.784
0.753    0.964     0.672     line_abreast_formation
                 0.899    0.025    0.849      0.899    0.873
0.853    0.988     0.961     vehicle
Weighted Avg. 0.803    0.028    0.808      0.803    0.801
0.776    0.978     0.850

=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
  89   0   1   3  27   0   0   0 |   a = freeze
   0  75  24   0   0   0   0  20 |   b = rally_point
   8   1 109   0   4   0   0   1 |   c = hurry_up
   2   0   1 119   2   2   0   1 |   d = down
  28   0   0   0 102   0   0   0 |   e = come
   0   0   0   1   0  88  41   0 |   f = stop
   0   0   1   2   0  17 111   0 |   g = line_abreast_formation
   0  10   4   0   0   0   0 124 |   h = vehicle
```

In addition to the 7.7554% accuracy improvement, there are changes in the confusion matrix.

For example, before removing unusual samples, the Freeze gesture was misclassified as Vehicle (30 times), Hurry Up (27 times), Come (12 times), and

Rally Point (10 times). These misclassifications are intuitively unexpected because the Vehicle, Hurry Up, and Rally Point gestures are not similar to the Freeze gesture. However, after removing the unusual samples, the Freeze gesture was misclassified as Come (27 times), Down (3 times), and Hurry Up (1 time). These misclassifications are intuitively expected, because Freeze and Come gesture movements are very similar. (Appendix C categorizes all the unusual samples by gesture.)

5.2 Logistic Model Tree (LMT)

The LMT classifier was compared against the same classifier trained with the entire 1,360 data set. Using the 10-fold cross validation approach, the LMT trained with 1,360 samples scored 82.5% accuracy, while the LMT trained with 1,018 samples scored 7.4804 percentage points higher at 89.9804%.

The following are the statistics generated from the LMT classifier trained on the 1,360 sample and tested using 10-fold cross validation:

```
=== Summary ===
Correctly Classified Instances        1122               82.5    %
Incorrectly Classified Instances       238               17.5    %
Kappa statistic                          0.8
Mean absolute error                      0.0447
Root mean squared error                  0.1989
Relative absolute error                 20.4526 %
Root relative squared error             60.1505 %
Coverage of cases (0.95 level)          86.8382 %
Mean rel. region size (0.95 level)      14.0993 %
Total Number of Instances             1360

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.641    0.050    0.645      0.641    0.643
0.592    0.918     0.626     freeze
                 0.953    0.006    0.959      0.953    0.956
0.949    0.981     0.960     rally_point
                 0.688    0.039    0.718      0.688    0.703
0.661    0.923     0.689     hurry_up
                 0.976    0.002    0.988      0.976    0.982
0.980    0.997     0.992     down
                 0.794    0.042    0.730      0.794    0.761
0.726    0.949     0.778     come
                 0.888    0.019    0.868      0.888    0.878
0.860    0.978     0.864     stop
                 0.865    0.018    0.875      0.865    0.870
0.851    0.982     0.882     line_abreast_formation
                 0.794    0.024    0.823      0.794    0.808
0.782    0.957     0.817     vehicle
```

```
Weighted Avg. 0.825    0.025    0.826      0.825    0.825
0.800    0.961     0.826

=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
 109   2  18   0  24   0   0  17 |   a = freeze
   1 162   2   0   2   0   0   3 |   b = rally_point
  23   0 117   2  20   0   1   7 |   c = hurry_up
   0   0   0 166   0   0   3   1 |   d = down
  15   0  19   0 135   0   0   1 |   e = come
   2   1   0   0   0 151  16   0 |   f = stop
   1   0   0   0   0  22 147   0 |   g = line_abreast_formation
  18   4   7   0   4   1   1 135 |   h = vehicle
```

The following are the statistics generated from the LMT classifier trained on the vetted 1,018 sample and tested using 10-fold cross validation:

```
=== Summary ===
Correctly Classified Instances         916               89.9804 %
Incorrectly Classified Instances       102               10.0196 %
Kappa statistic                          0.8855
Mean absolute error                      0.0279
Root mean squared error                  0.1512
Relative absolute error                 12.7584 %
Root relative squared error             45.7143 %
Coverage of cases (0.95 level)          93.5167 %
Mean rel. region size (0.95 level)      14.0594 %
Total Number of Instances             1018

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.800    0.026    0.807      0.800    0.803
0.777    0.965     0.792     freeze
                 0.975    0.004    0.967      0.975    0.971
0.967    0.996     0.985     rally_point
                 0.976    0.006    0.960      0.976    0.968
0.963    0.992     0.984     hurry_up
                 0.953    0.008    0.945      0.953    0.949
0.942    0.989     0.926     down
                 0.846    0.024    0.840      0.846    0.843
0.820    0.976     0.846     come
                 0.808    0.014    0.897      0.808    0.850
0.831    0.982     0.903     stop
                 0.901    0.029    0.819      0.901    0.858
0.837    0.982     0.821     line_abreast_formation
                 0.942    0.005    0.970      0.942    0.956
0.949    0.981     0.973     vehicle
Weighted Avg. 0.900    0.014    0.901      0.900    0.900
0.886    0.983     0.904
```

```
=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
  96   0   2   1  21   0   0   0 |   a = freeze
   0 116   0   0   0   0   0   3 |   b = rally_point
   1   0 120   1   0   0   0   1 |   c = hurry_up
   3   0   1 121   0   0   2   0 |   d = down
  18   1   1   0 110   0   0   0 |   e = come
   0   0   0   1   0 105  24   0 |   f = stop
   0   0   0   1   0  12 118   0 |   g = line_abreast_formation
   1   3   1   3   0   0   0 130 |   h = vehicle
```

5.3 K-Nearest Neighbor (IBK)

The IBK classifier was compared against the same classifier trained with the entire 1,360 data set. Using the 10-fold cross validation approach, the IBK trained with 1,360 samples scored 93.2353% accuracy, while the IBK trained with 1,018 samples scored 5.809 percentage points lower at 87.4263%.

The following are the statistics generated from the IBK classifier trained on the 1,360 sample and tested using 10-fold cross validation:

```
=== Summary ===
Correctly Classified Instances        1268               93.2353 %
Incorrectly Classified Instances        92                6.7647 %
Kappa statistic                          0.9227
Mean absolute error                      0.0182
Root mean squared error                  0.1296
Relative absolute error                  8.3298 %
Root relative squared error             39.1995 %
Coverage of cases (0.95 level)          93.2353 %
Mean rel. region size (0.95 level)      12.5    %
Total Number of Instances             1360

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.906    0.017    0.885      0.906    0.895
0.880    0.945     0.815     freeze
                 0.959    0.003    0.982      0.959    0.970
0.966    0.978     0.947     rally_point
                 0.900    0.010    0.927      0.900    0.913
0.901    0.945     0.847     hurry_up
                 0.976    0.001    0.994      0.976    0.985
0.983    0.988     0.974     down
                 0.935    0.013    0.909      0.935    0.922
0.910    0.961     0.858     come
                 0.882    0.010    0.926      0.882    0.904
0.891    0.936     0.832     stop
                 0.935    0.018    0.883      0.935    0.909
0.896    0.959     0.834     line_abreast_formation
```

```
                 0.965    0.006    0.959      0.965    0.962
0.956    0.979     0.930     vehicle
Weighted Avg. 0.932    0.010    0.933      0.932    0.932
0.923    0.961     0.879

=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
 154   0   5   0   6   0   0   5 |   a = freeze
   2 163   2   0   2   0   0   1 |   b = rally_point
   8   1 153   0   7   0   0   1 |   c = hurry_up
   0   0   0 166   0   1   3   0 |   d = down
   5   1   5   0 159   0   0   0 |   e = come
   1   0   0   1   0 150  18   0 |   f = stop
   0   0   0   0   0  11 159   0 |   g = line_abreast_formation
   4   1   0   0   1   0   0 164 |   h = vehicle
```

The following are the statistics generated from the IBK classifier trained on the vetted 1,018 sample and tested using 10-fold cross validation:

```
=== Summary ===
Correctly Classified Instances         890               87.4263 %
Incorrectly Classified Instances       128               12.5737 %
Kappa statistic                          0.8563
Mean absolute error                      0.0331
Root mean squared error                  0.1766
Relative absolute error                 15.1157 %
Root relative squared error             53.3919 %
Coverage of cases (0.95 level)          87.4263 %
Mean rel. region size (0.95 level)      12.5    %
Total Number of Instances             1018

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.850    0.040    0.739      0.850    0.791
0.763    0.903     0.649     freeze
                 0.941    0.010    0.926      0.941    0.933
0.924    0.963     0.884     rally_point
                 0.894    0.010    0.924      0.894    0.909
0.897    0.940     0.840     hurry_up
                 0.913    0.009    0.935      0.913    0.924
0.914    0.952     0.857     down
                 0.792    0.019    0.858      0.792    0.824
0.800    0.884     0.712     come
                 0.831    0.025    0.831      0.831    0.831
0.806    0.905     0.723     stop
                 0.824    0.029    0.806      0.824    0.815
0.787    0.904     0.694     line_abreast_formation
                 0.949    0.001    0.992      0.949    0.970
0.966    0.975     0.945     vehicle
Weighted Avg. 0.874    0.018    0.878      0.874    0.875
0.858    0.928     0.789
```

```
=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
 102   0   3   1  14   0   0   0 |   a = freeze
   2 112   3   1   0   0   0   1 |   b = rally_point
   7   1 110   2   3   0   0   0 |   c = hurry_up
   3   1   1 116   0   2   4   0 |   d = down
  24   2   1   0 103   0   0   0 |   e = come
   0   0   0   0   0 108  22   0 |   f = stop
   0   0   0   3   0  20 108   0 |   g = line_abreast_formation
   0   5   1   1   0   0   0 131 |   h = vehicle
```

5.4 Ensemble Classifier Accuracy

The vetted samples were tested further with a more complex classifier. The 1,018 vetted samples were used to train a Voting classifier configured to use LMT, IBK, and NB. The Voting classifier was compared against the same classifier trained with the entire 1,360 data set. Using the 10-fold cross validation approach, the Voting model trained with 1,360 samples scored 89.5588% accuracy, while the Voting model trained with 1,018 samples scored 0.7162% higher at 90.275%.

The following are the statistics generated from the Voting classifier trained on the 1,360 sample and tested using 10-fold cross validation:

```
=== Stratified cross-validation ===
=== Summary AFTER Voting classifier combining LMT + IBK + NB ===

Correctly Classified Instances        1218               89.5588 %
Incorrectly Classified Instances       142               10.4412 %
Kappa statistic                          0.8807
Mean absolute error                      0.0488
Root mean squared error                  0.1401
Relative absolute error                 22.3254 %
Root relative squared error             42.3531 %
Coverage of cases (0.95 level)          99.1912 %
Mean rel. region size (0.95 level)      23.0331 %
Total Number of Instances             1360

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.800    0.028    0.805      0.800    0.802
0.774    0.982     0.880     freeze
                 0.965    0.002    0.988      0.965    0.976
0.973    0.998     0.994     rally_point
                 0.794    0.015    0.882      0.794    0.836
0.815    0.990     0.937     hurry_up
                 1.000    0.001    0.994      1.000    0.997
0.997    1.000     1.000     down
                 0.912    0.023    0.852      0.912    0.881
0.864    0.992     0.960     come
```

```
                 0.871    0.015    0.892      0.871    0.881
0.864    0.992     0.958     stop
                 0.894    0.017    0.884      0.894    0.889
0.873    0.994     0.945     line_abreast_formation
                 0.929    0.019    0.873      0.929    0.900
0.886    0.996     0.974     vehicle
Weighted Avg. 0.896    0.015    0.896      0.896    0.895
0.881    0.993     0.956

=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
 136   1   7   0  13   0   0  13 |   a = freeze
   1 164   1   0   1   0   0   3 |   b = rally_point
  17   0 135   0  12   0   0   6 |   c = hurry_up
   0   0   0 170   0   0   0   0 |   d = down
   6   0   8   0 155   0   0   1 |   e = come
   1   0   0   1   0 148  20   0 |   f = stop
   0   0   0   0   0  18 152   0 |   g = line_abreast_formation
   8   1   2   0   1   0   0 158 |   h = vehicle
```

The following are the statistics generated from the Voting classifier trained on the vetted 1,018 sample and tested using 10-fold cross validation:

```
=== Summary ===

Correctly Classified Instances         919               90.275  %
Incorrectly Classified Instances        99                9.725  %
Kappa statistic                          0.8888
Mean absolute error                      0.0396
Root mean squared error                  0.1351
Relative absolute error                 18.1213 %
Root relative squared error             40.8579 %
Coverage of cases (0.95 level)          99.6071 %
Mean rel. region size (0.95 level)      18.8605 %
Total Number of Instances             1018

=== Detailed Accuracy By Class ===

                 TP Rate  FP Rate  Precision  Recall   F-Measure
MCC      ROC Area  PRC Area  Class
                 0.850    0.026    0.816      0.850    0.833
0.810    0.987     0.902     freeze
                 0.958    0.007    0.950      0.958    0.954
0.948    0.999     0.994     rally_point
                 0.959    0.004    0.967      0.959    0.963
0.958    1.000     0.998     hurry_up
                 0.969    0.007    0.953      0.969    0.961
0.955    1.000     0.997     down
                 0.869    0.020    0.863      0.869    0.866
0.846    0.990     0.918     come
                 0.792    0.015    0.888      0.792    0.837
0.817    0.987     0.934     stop
                 0.885    0.030    0.811      0.885    0.847
0.824    0.986     0.870     line_abreast_formation
```

```
                 0.942    0.002    0.985      0.942    0.963
0.958    1.000     0.997     vehicle
Weighted Avg. 0.903    0.014    0.904      0.903    0.903
0.889    0.993     0.951

=== Confusion Matrix ===

   a   b   c   d   e   f   g   h   <-- classified as
 102   0   1   0  17   0   0   0 |   a = freeze
   0 114   2   1   0   0   0   2 |   b = rally_point
   4   0 118   0   1   0   0   0 |   c = hurry_up
   3   0   0 123   0   0   1   0 |   d = down
  16   0   1   0 113   0   0   0 |   e = come
   0   0   0   1   0 103  26   0 |   f = stop
   0   0   0   2   0  13 116   0 |   g = line_abreast_formation
   0   6   0   2   0   0   0 130 |   h = vehicle
```

6. Conclusion

By cleaning up the gesture data set, most of the tested classifiers saw an improvement in their accuracy. The improvement in the LMT and NB classifiers, which try to fit the data to some underlying model, may be due to fact that by cleaning up the data it was much easier to fit them to a single simple model. However, IBK, which classifies solely based on distance measurements, may suffer from the lack of variability if one or a set of test gestures is different from the gestures it was trained on. Regardless of whether cleaning up the data set improved or reduced the accuracy of the individual classifiers, it did have a substantial impact on the accuracy. In the case of the ensemble classifier, the same cannot be said. Cleaning up the data set lead to only moderate improvements in the accuracy. Because the ensemble classifier tries to take the best of each of the constituent classifiers, it may be complex enough to actually compensate for the unclean data in the raw data set. Thus, by cleaning up the data set, only moderate improvement in accuracy is achieved. It is of note, however, that for the cleaned-up data set the ensemble classifier performs slightly better than any individual classifier.

Data analysis is an important part of conducting an experiment. It may reveal trends and patterns in the data not immediately apparent to the investigator. Understanding the data can help identify and segregate unusual data that negatively affect predictive model training. In machine learning, abnormal data can hinder predictive models and result in less-accurate classifiers. ARL analyzed the pitch and xAccel_g features of the NATO gesture movement data set to identify samples that did not conform to the general trend of the whole data set. This information was used to adjust how the classifiers were trained and affected the accuracy of the classifiers.

7. References

1. Lee M, Rao N. Hand gesture data collection procedure using a Myo armband for machine learning. Adelphi (MD): Army Research Laboratory (US); 2015. Report No.: ARL-TN-0699.

2. Lee M, Harrison A, Winkler R. Squad-level command and control using the Myo for tactical hand signal recognition. International Command and Control Research and Technology Symposium (ICCRTS); 2016 Sep 6–8; London, UK.

3. Weka. Weka 3: data mining software in Java. Hamilton (New Zealand): University of Waikato; n.d. [accessed 2016 Dec]. http://www.cs.waikato.ac.nz/ml/weka/.

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Appendix A. Charts Exhibiting Unusual Pitch Behavior

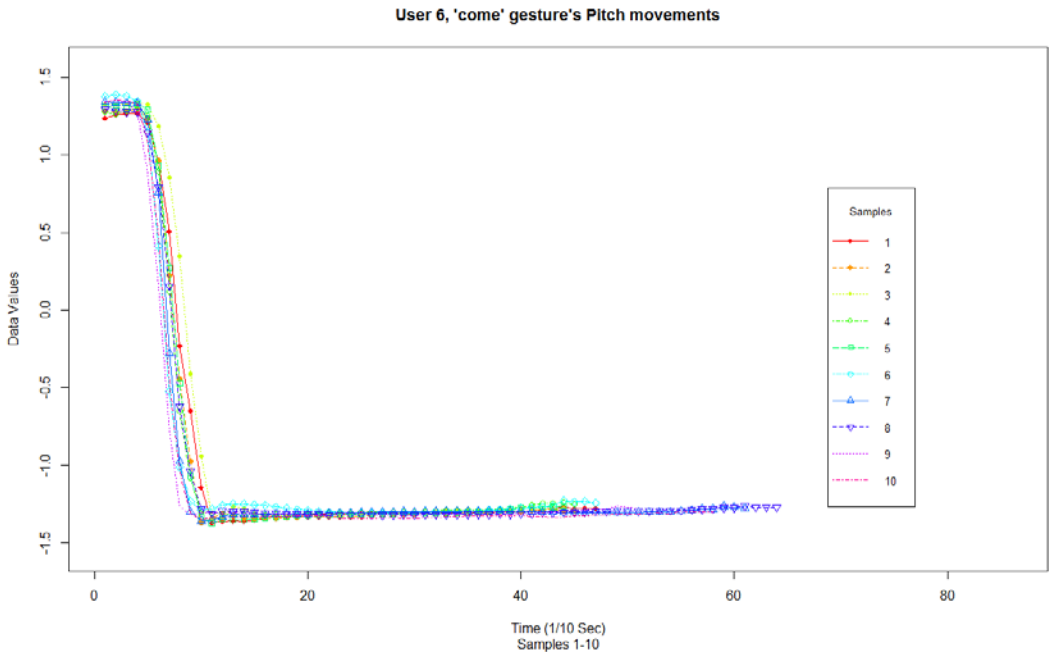

Fig. A-1 Come gesture, pitch feature, user 06. All samples exhibit reversed movement.

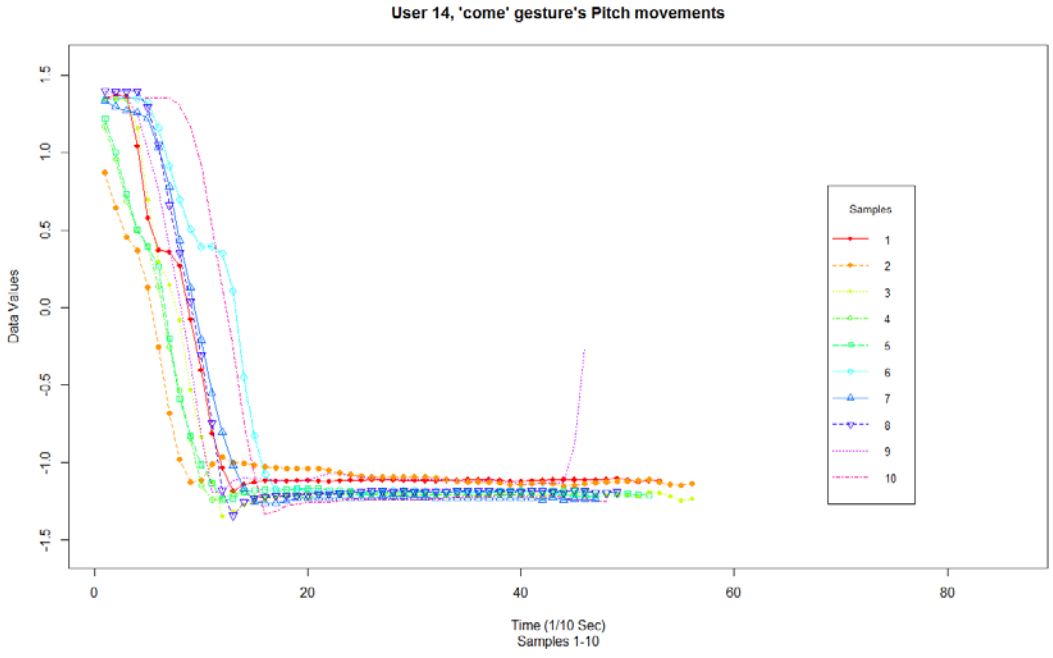

Fig. A-2 Come gesture, pitch feature, user 14. All samples exhibit reversed movement.

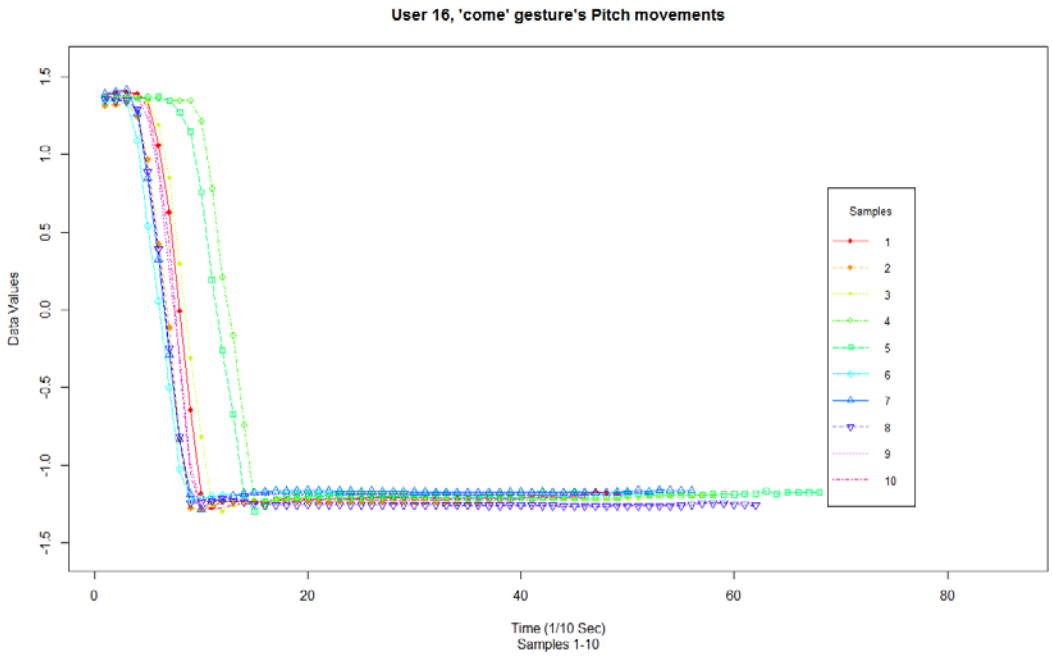

Fig. A-3 Come gesture, pitch feature, user 16. All samples exhibit reversed movement.

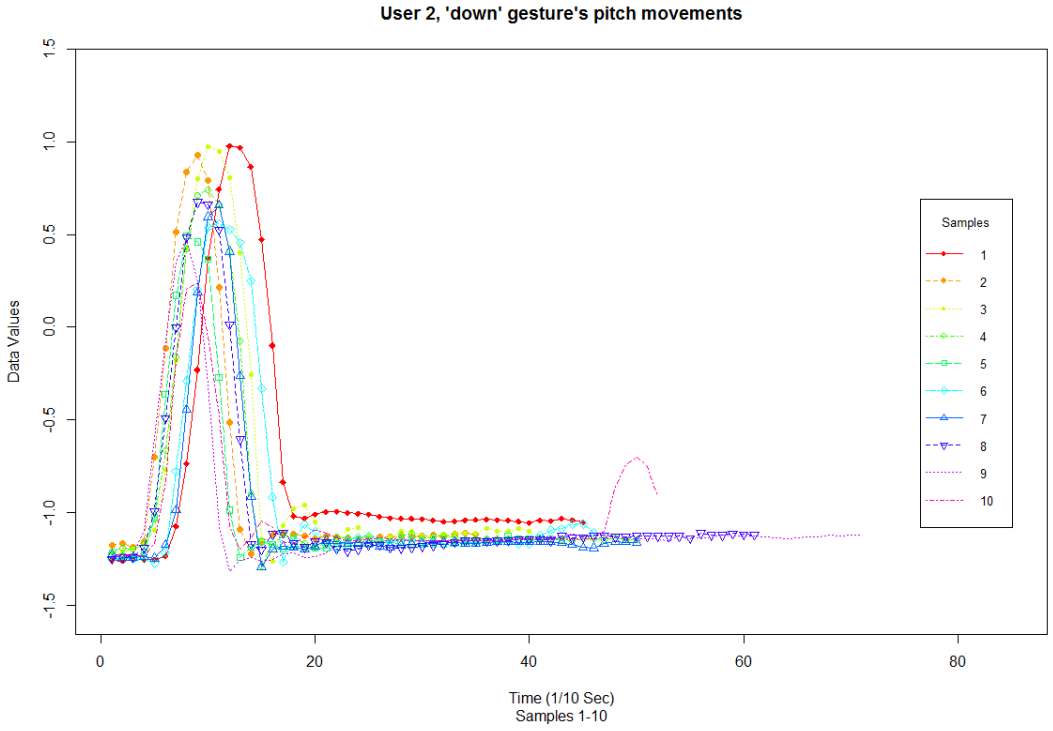

Fig. A-4 Down gesture, pitch feature, user 02. Sample 10 exhibit unusual movement at the end.

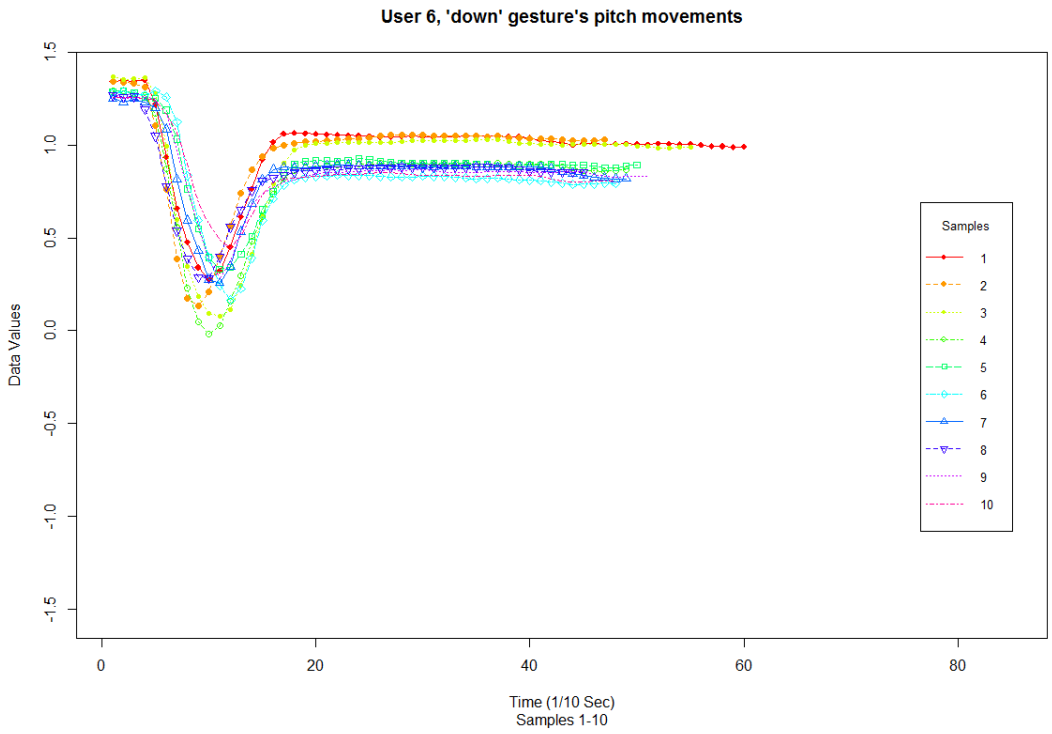

Fig. A-5 Down gesture, pitch feature, user 06. All samples exhibit reversed movement.

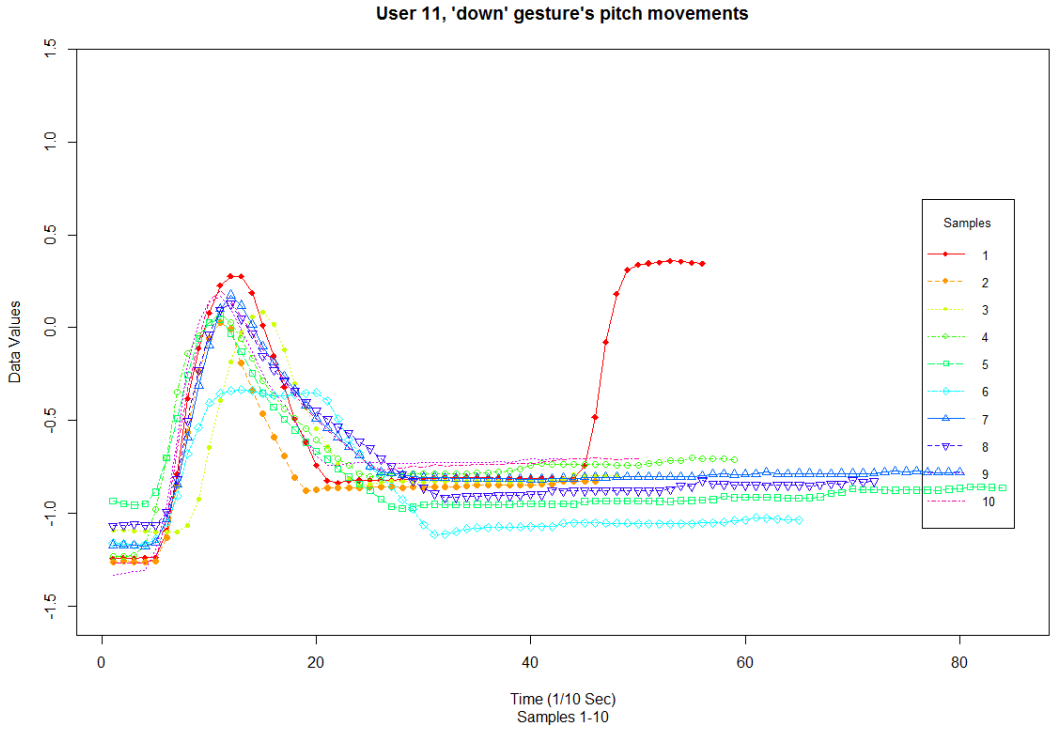

Fig. A-6 Down gesture, pitch feature, user 11. Sample 01 exhibit unusual movement at the end.

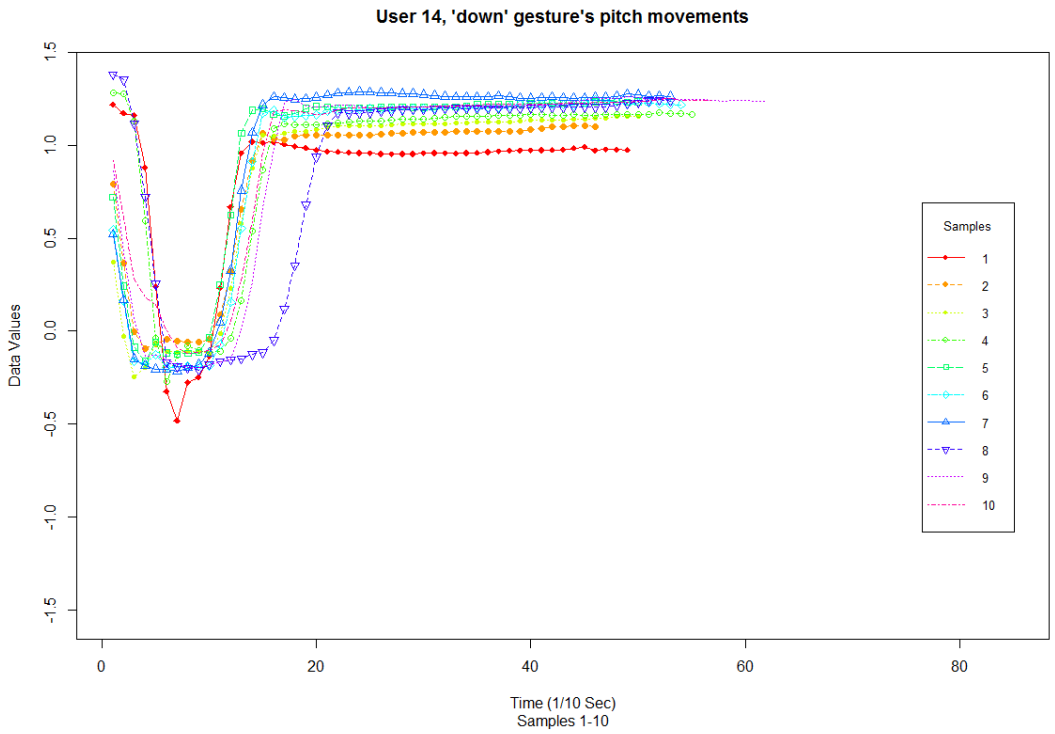

Fig. A-7 Down gesture, pitch feature, user 14. All samples exhibit reversed movement.

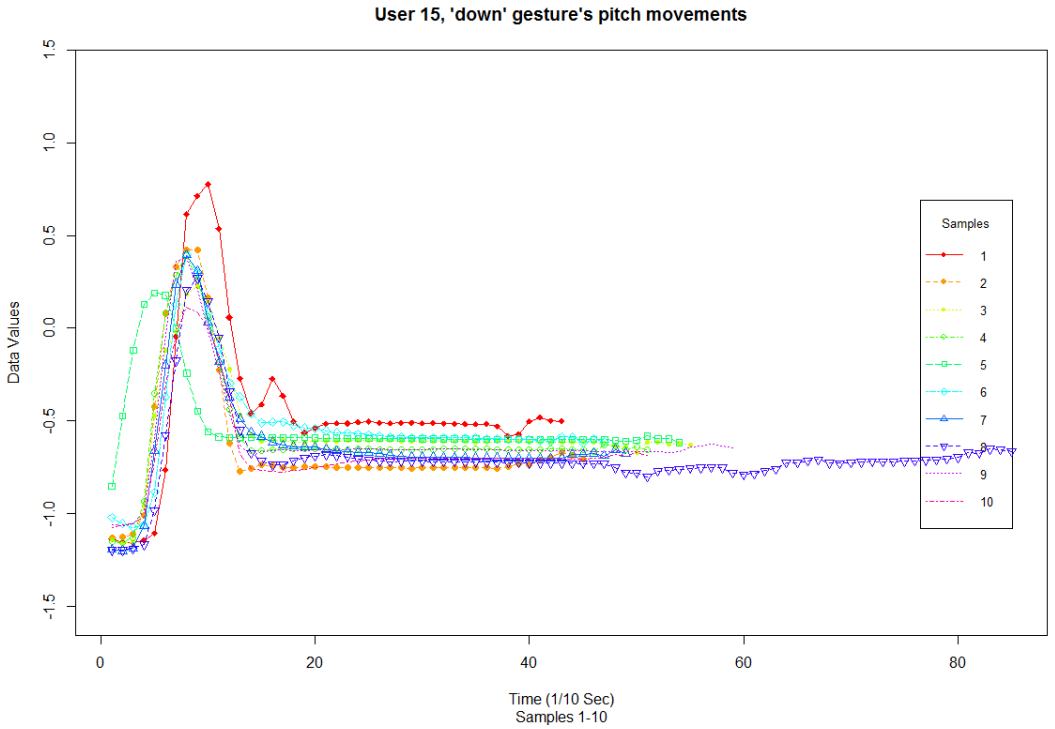

Fig. A-8 Down gesture, pitch feature, user 02. Sample 08 exhibit unusual movement at the end.

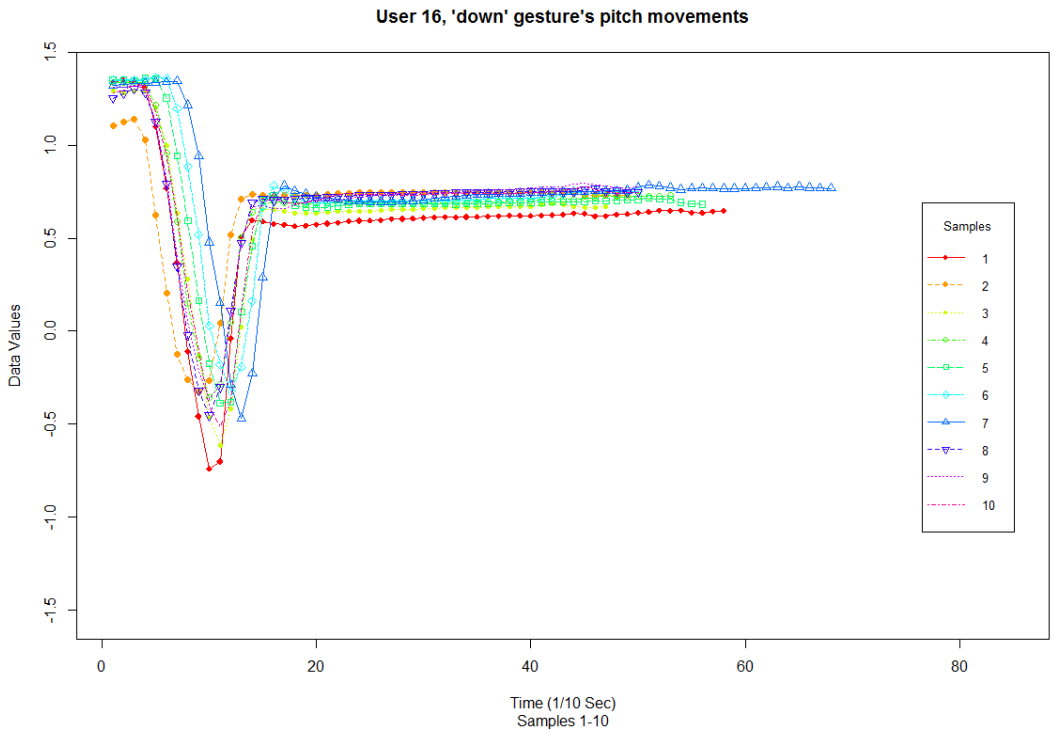

Fig. A-9 Down gesture, pitch feature, user 16. All samples exhibit reversed movement.

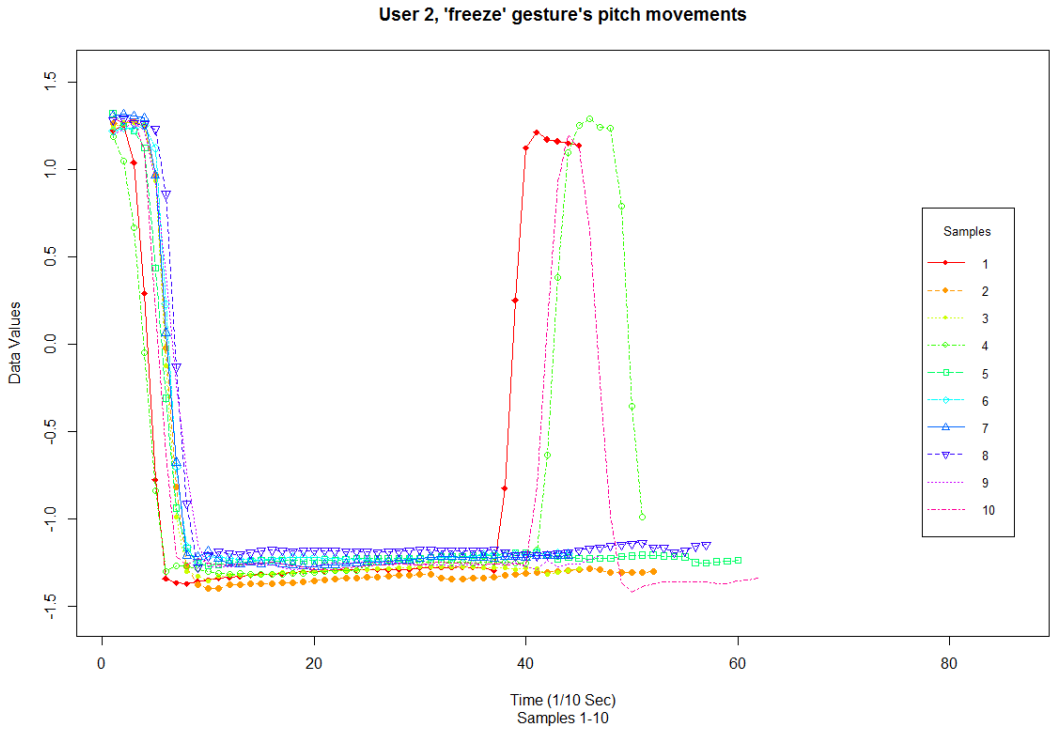

Fig. A-10 Freeze gesture, pitch feature, user 02. All samples exhibit reversed movement.

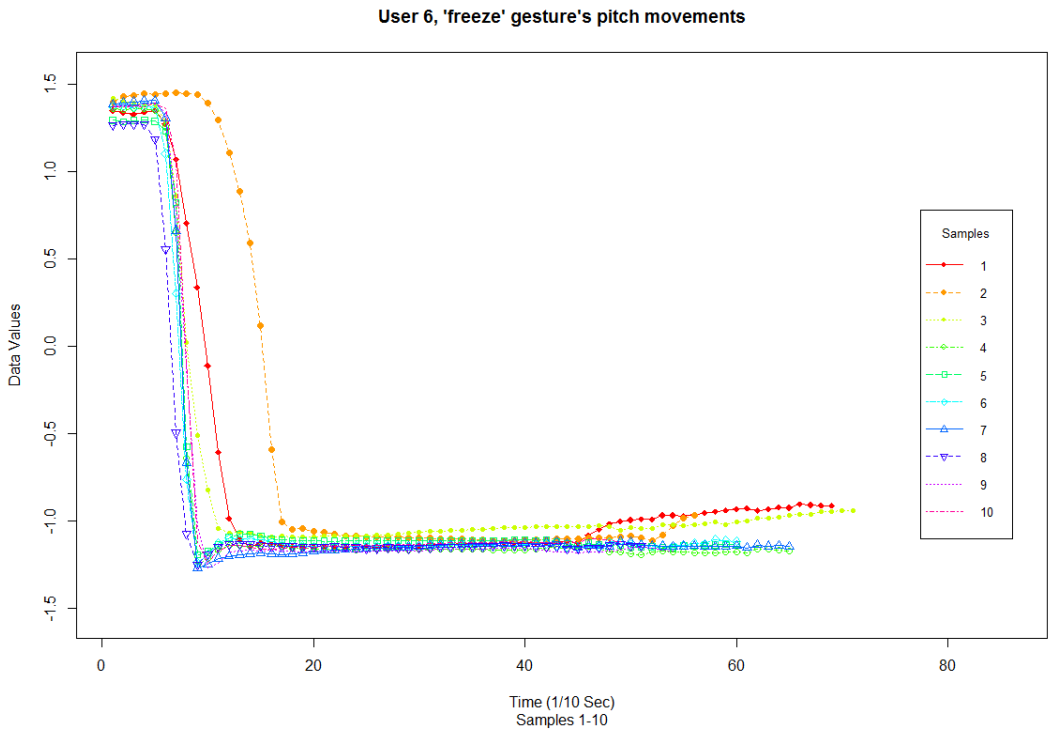

Fig. A-11 Freeze gesture, pitch feature, user 06. All samples exhibit reversed movement.

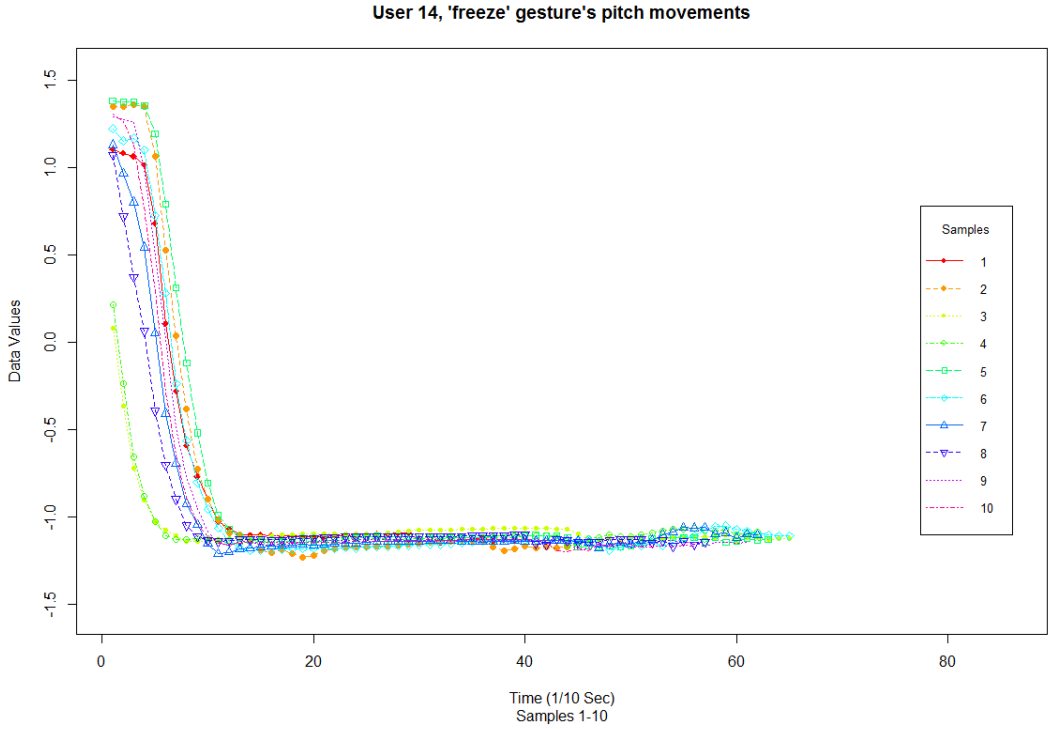

Fig. A-12 Freeze gesture, pitch feature, user 14. All samples exhibit reversed movement.

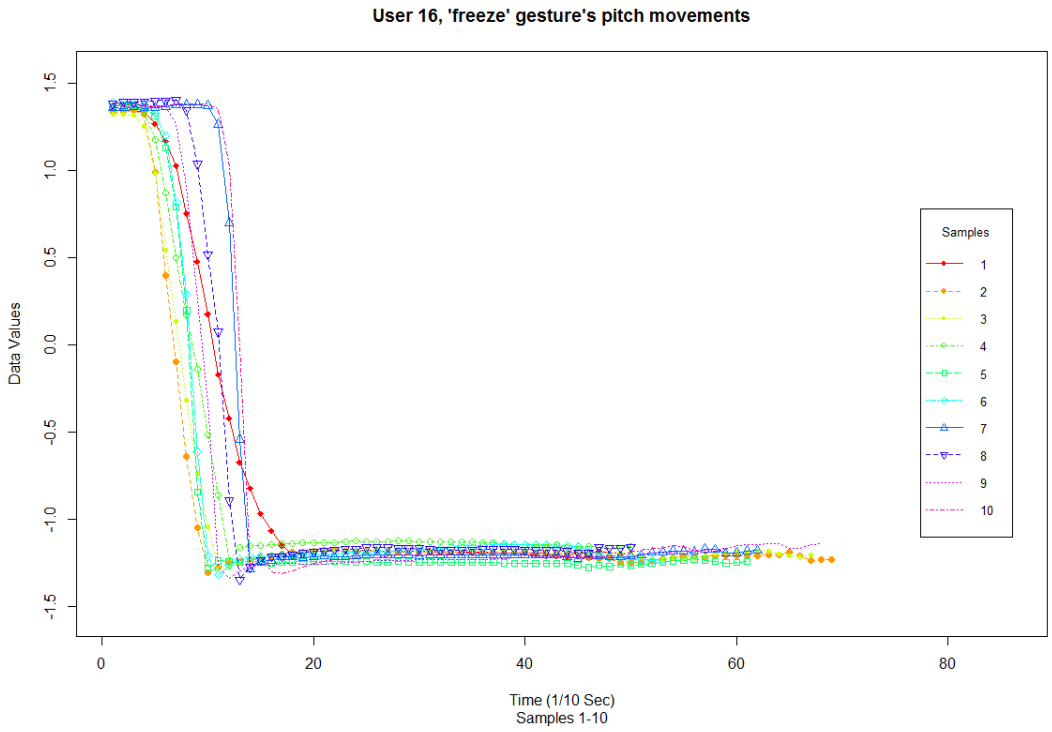

Fig. A-13 Freeze gesture, pitch feature, user 16. All samples exhibit reversed movement.

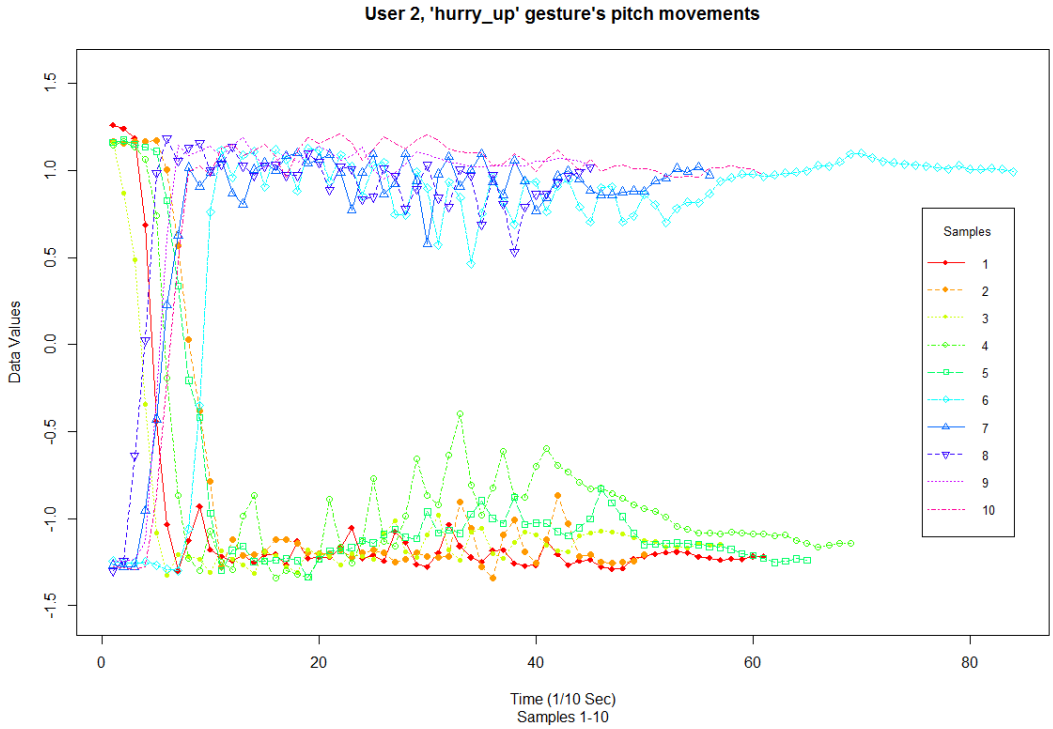

Fig. A-14 Hurry up gesture, pitch feature, user 02. Sample 01-05 exhibit reversed movement.

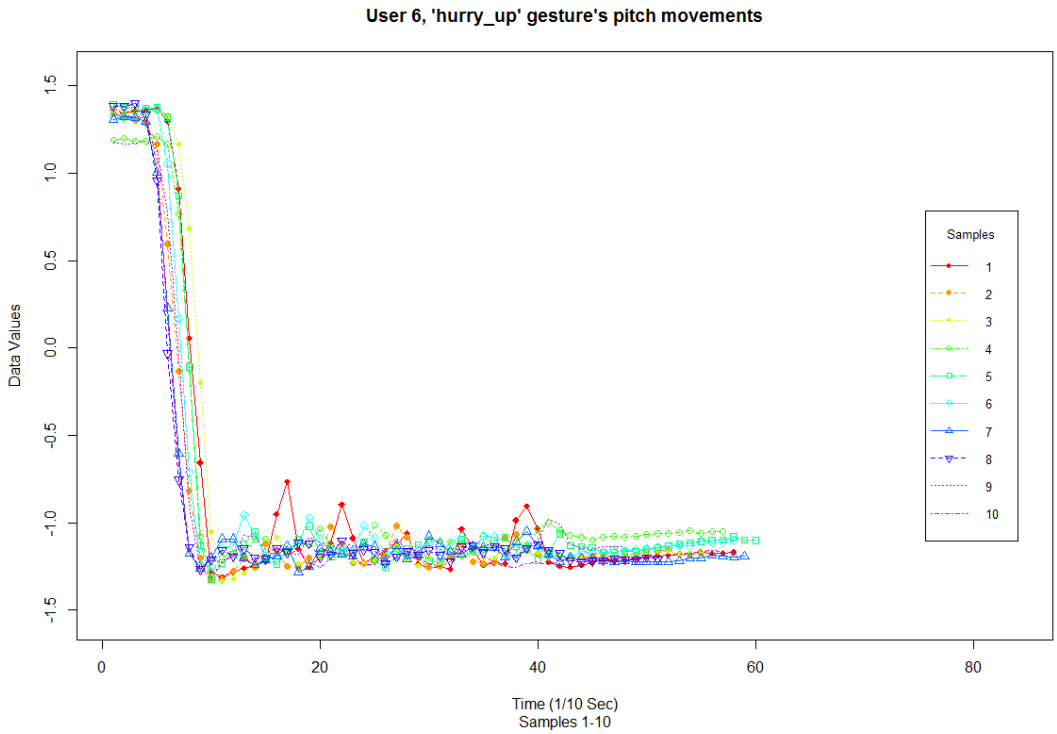

Fig. A-15 Hurry up gesture, pitch feature, user 06. All samples exhibit reversed movement.

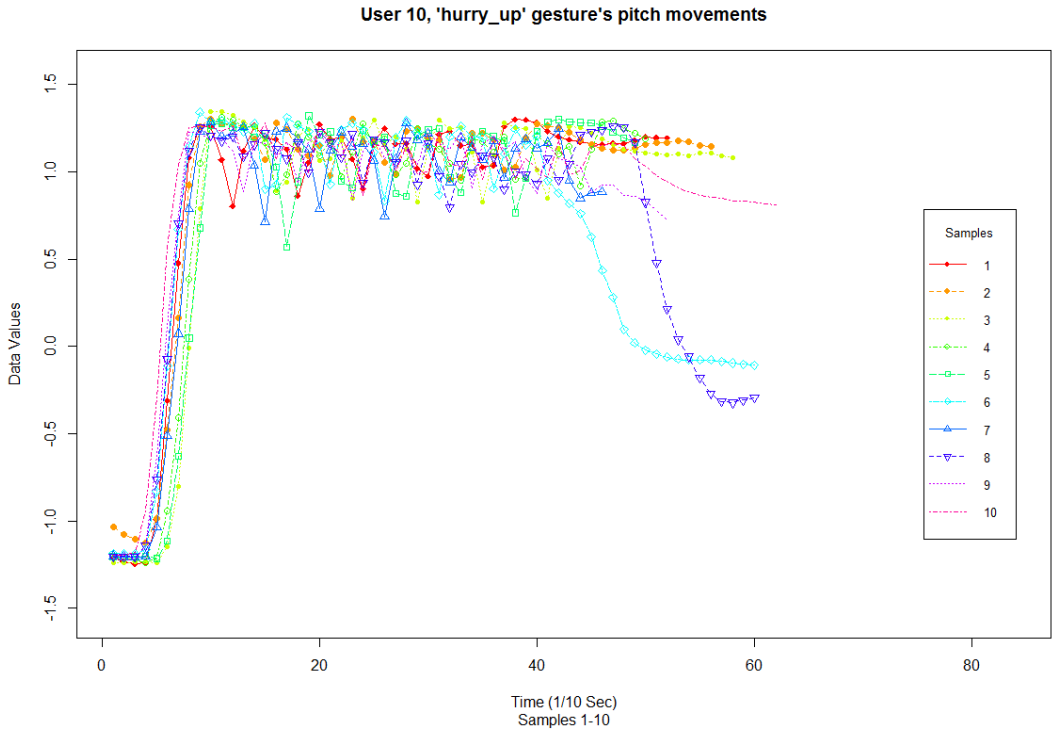

Fig. A-16 Hurry up gesture, pitch feature, user 10. Sample 06 and 08 exhibit unusual movement at the end.

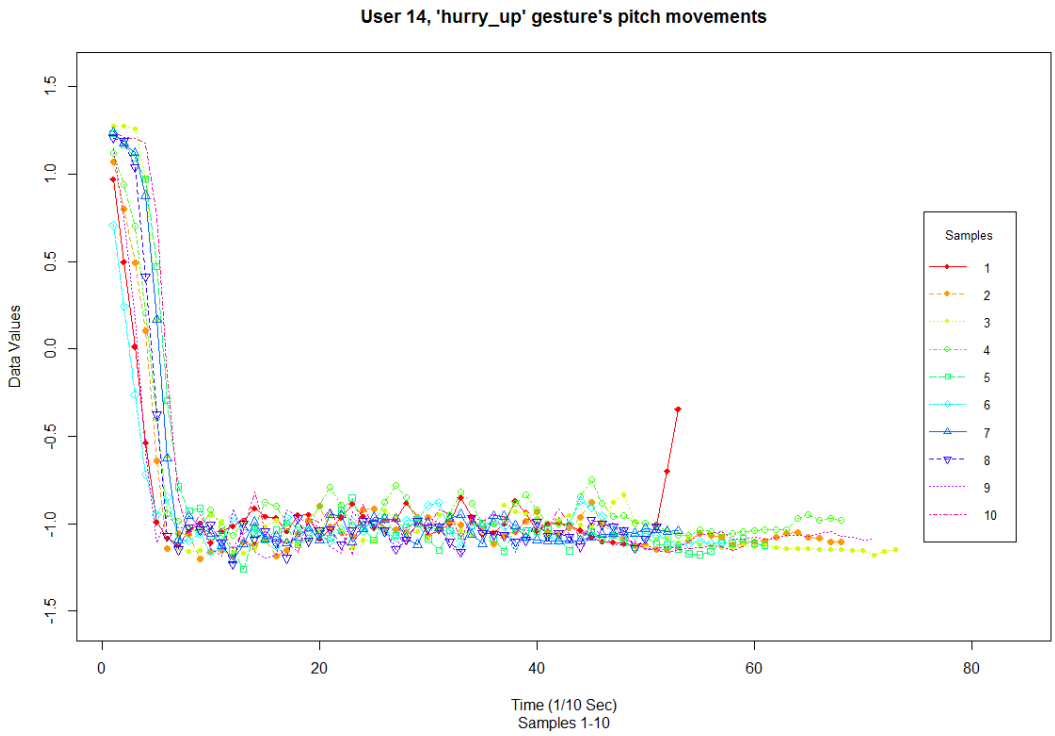

Fig. A-17 Hurry up gesture, pitch feature, user 14. All samples exhibit reversed movement.

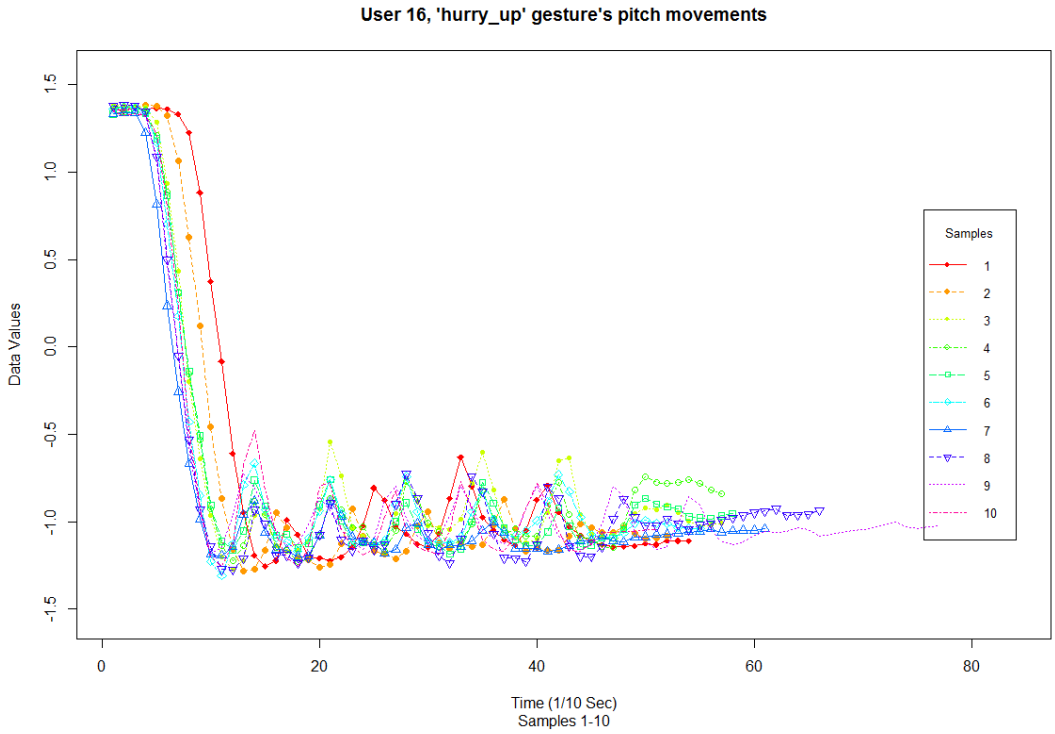

Fig. A-18 Hurry up gesture, pitch feature, user 16. All samples exhibit reversed movement.

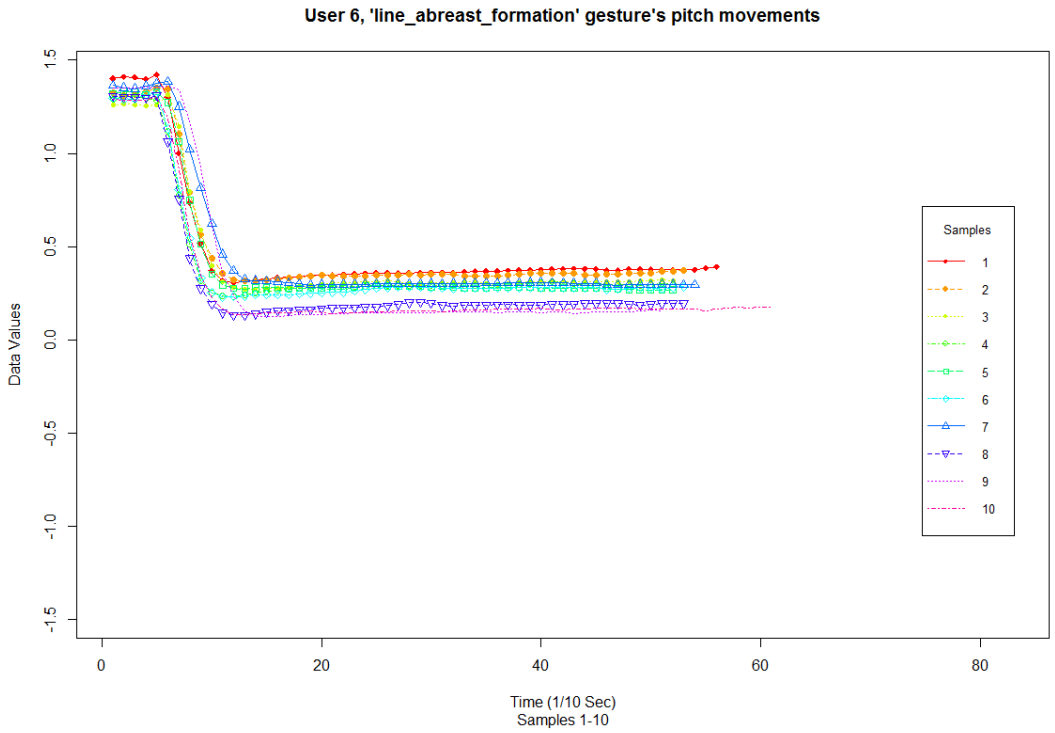

Fig. A-19 Line abreast formation gesture, pitch feature, user 06. All samples exhibit reversed movement.

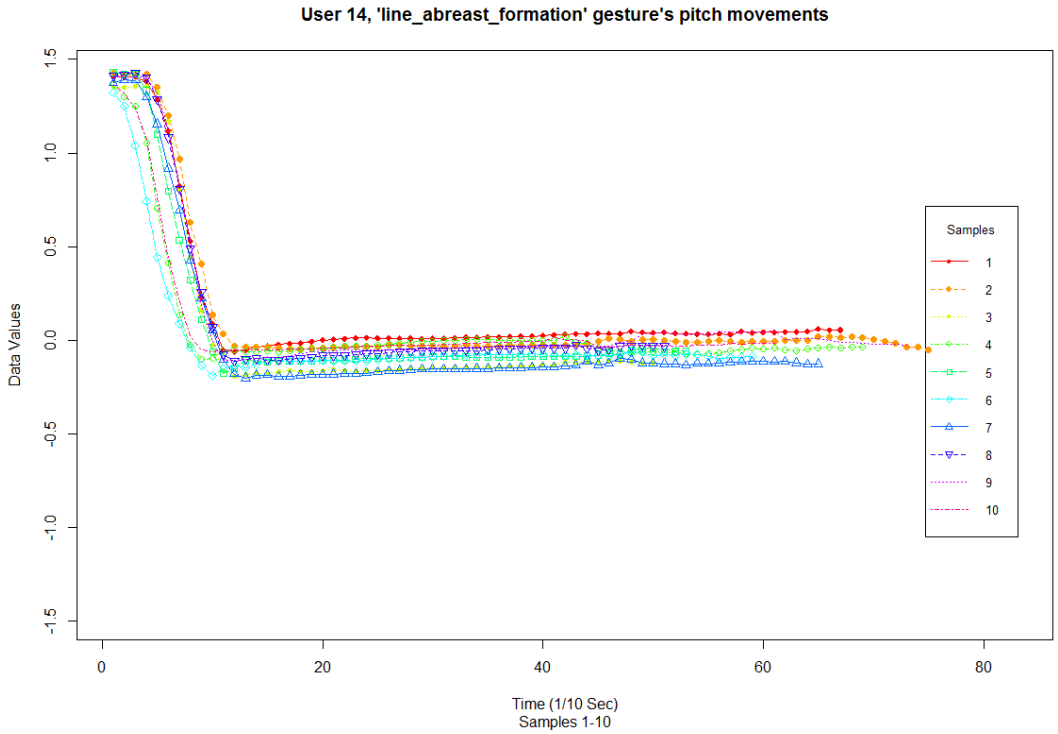

Fig. A-20 Line abreast formation gesture, pitch feature, user 14. All samples exhibit reversed movement.

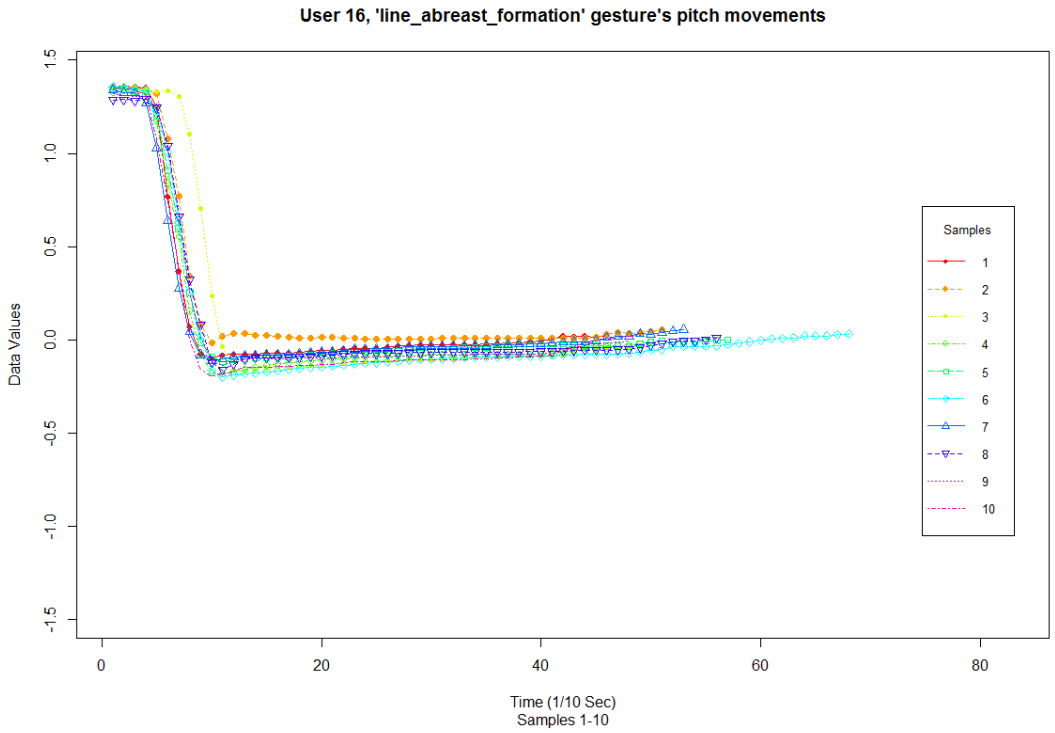

Fig. A-21 Line abreast formation gesture, pitch feature, user 16. All samples exhibit reversed movement.

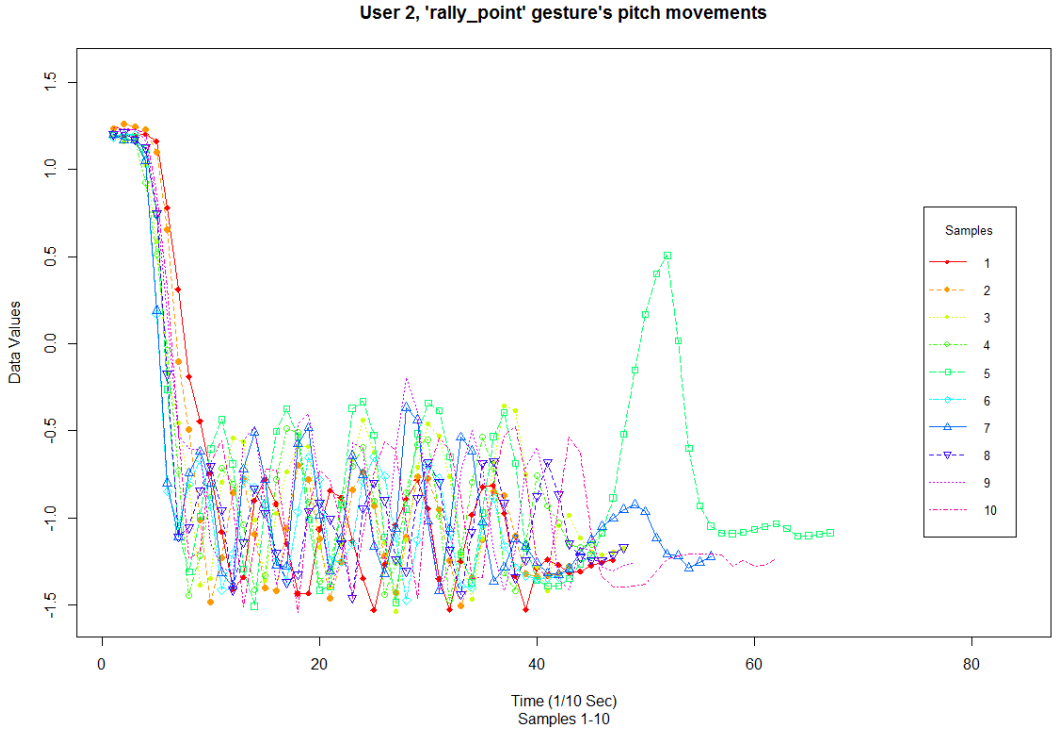

Fig. A-22 Rally point gesture, pitch feature, user 02. All samples exhibit reversed movement.

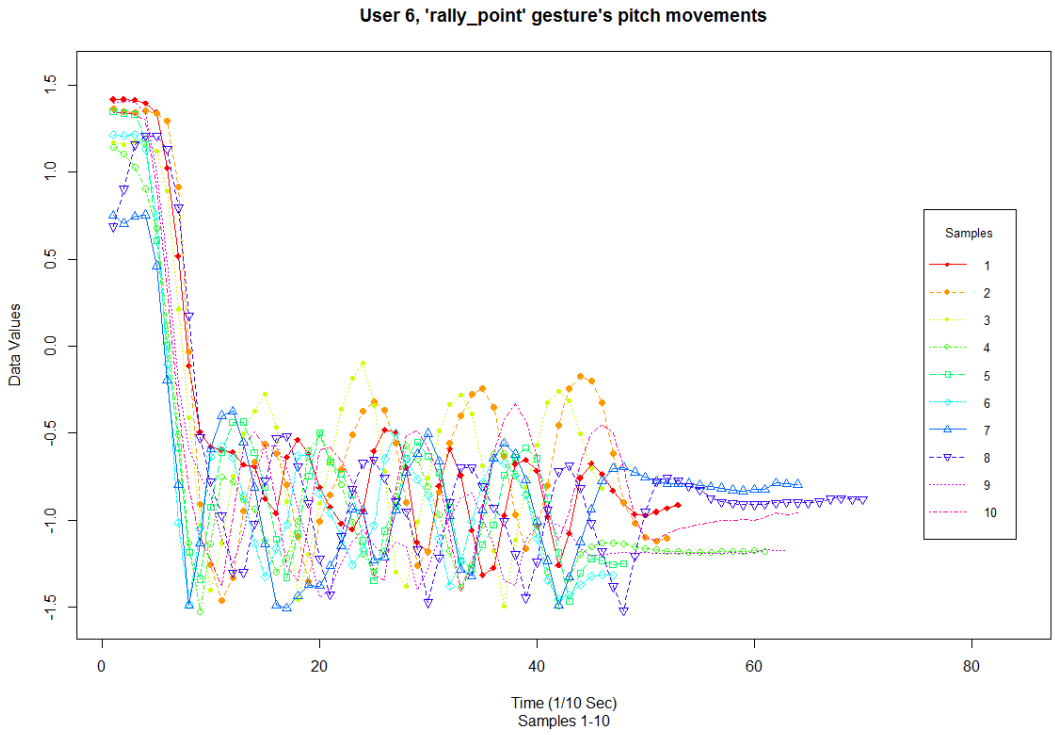

Fig. A-23 Rally point gesture, pitch feature, user 06. All samples exhibit reversed movement.

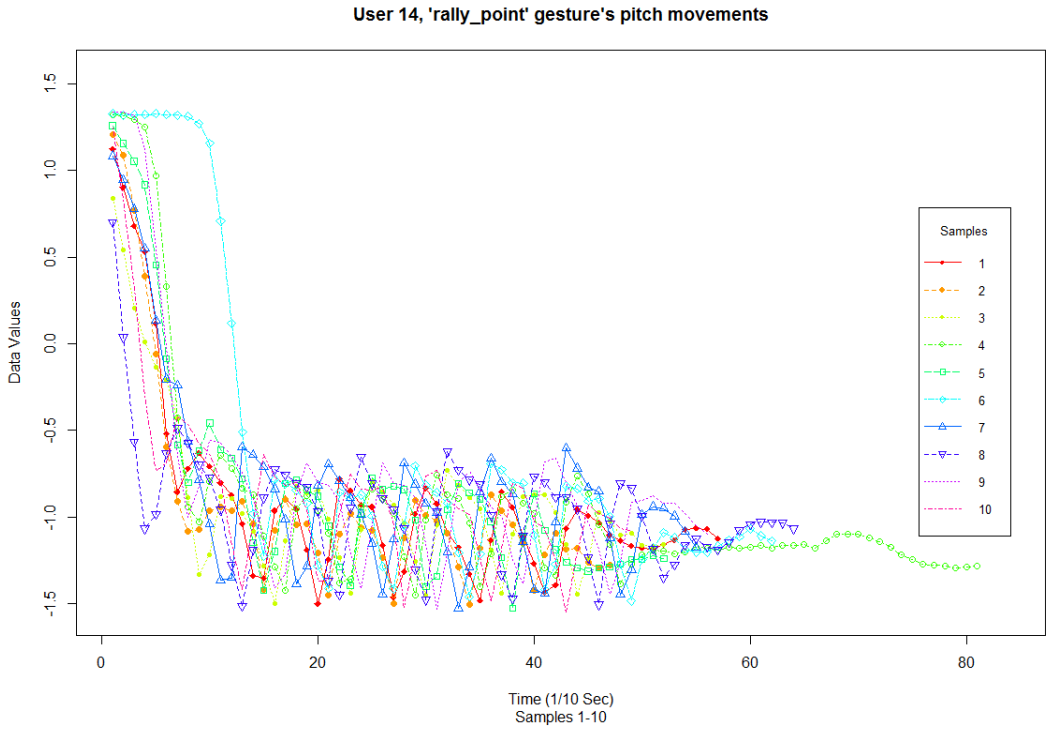

Fig. A-24 Rally point gesture, pitch feature, user 14. All samples exhibit reversed movement.

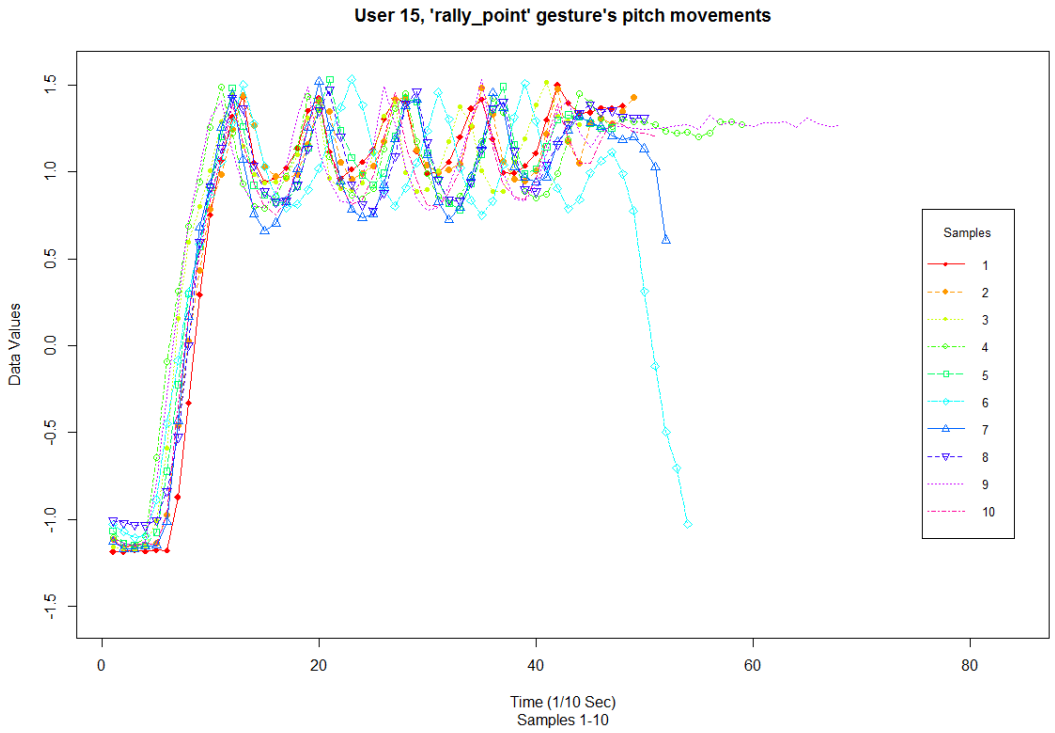

Fig. A-25 Rally point gesture, pitch feature, user 15. Sample 06 exhibit unusual movement at the end.

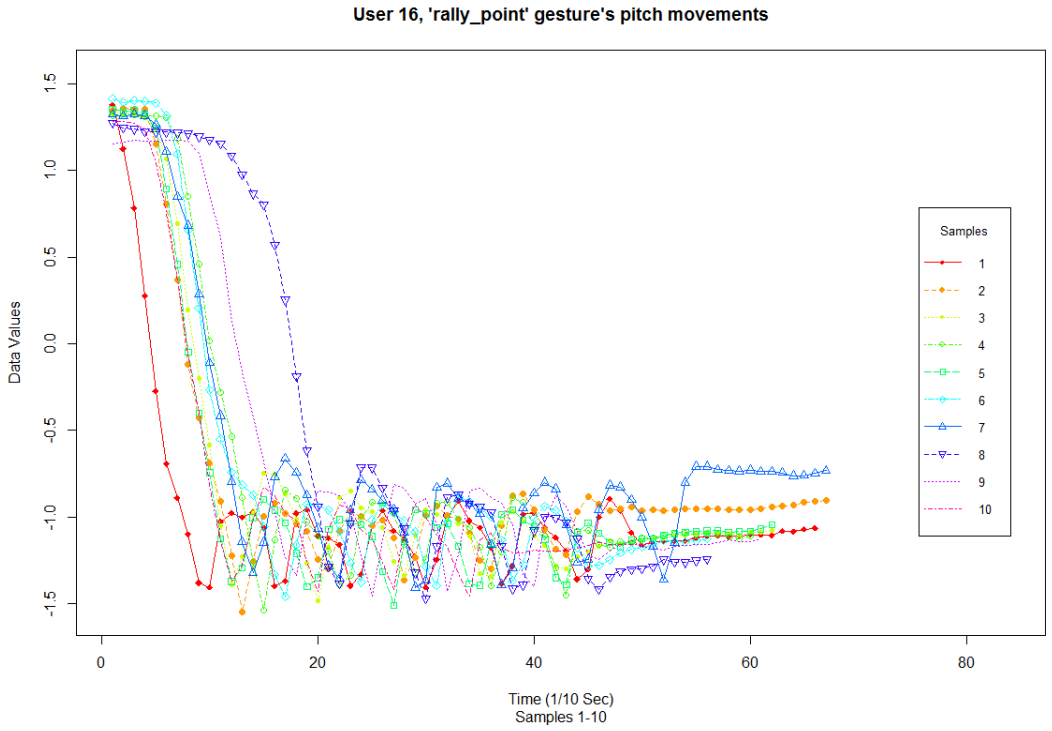

Fig. A-26 Rally point gesture, pitch feature, user 16. All samples exhibit reversed movement.

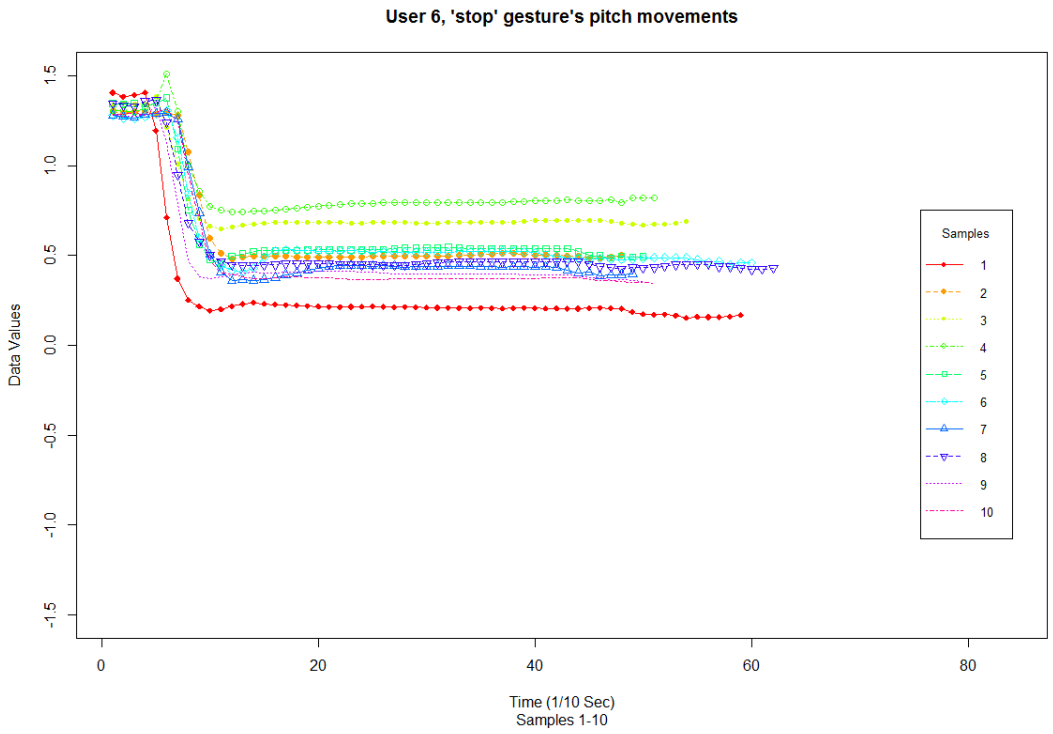

Fig. A-27 Stop gesture, pitch feature, user 06. All samples exhibit reversed movement.

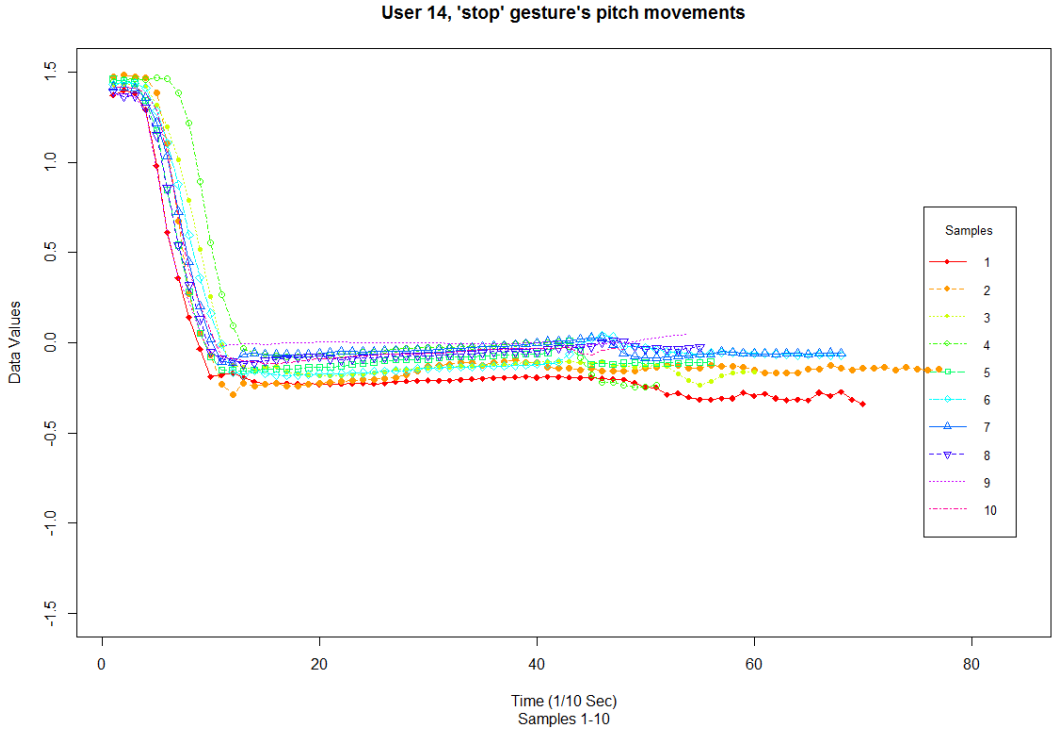

Fig. A-28 Stop gesture, pitch feature, user 14. All samples exhibit reversed movement.

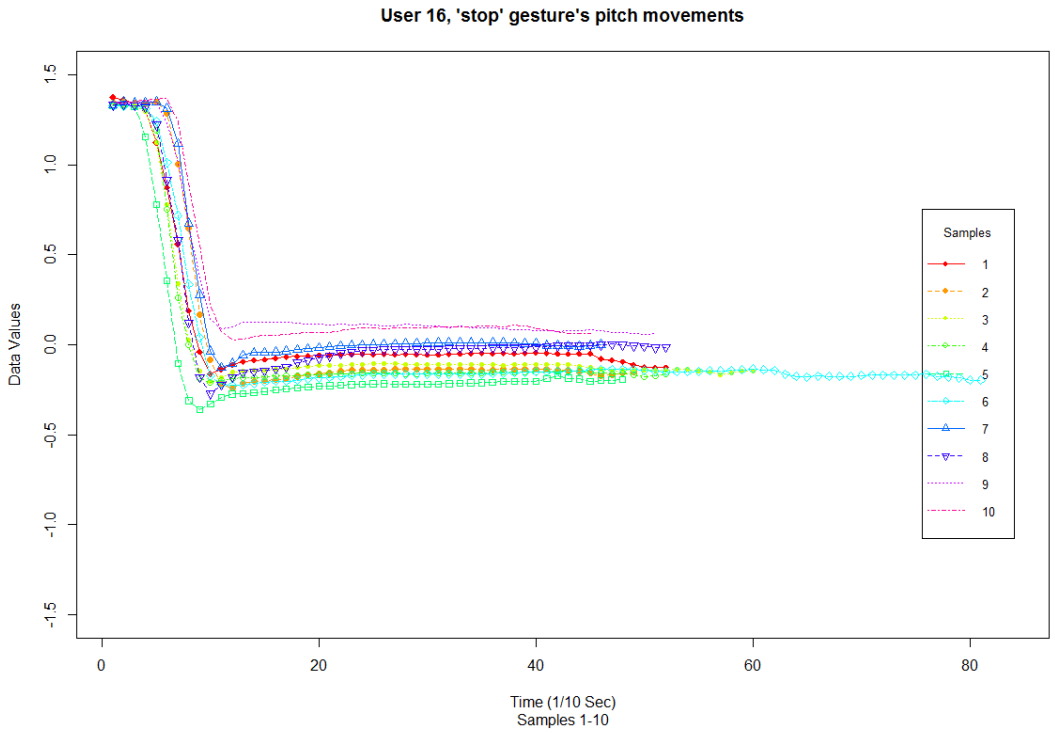

Fig. A-29 Stop gesture, pitch feature, user 16. All samples exhibit reversed movement.

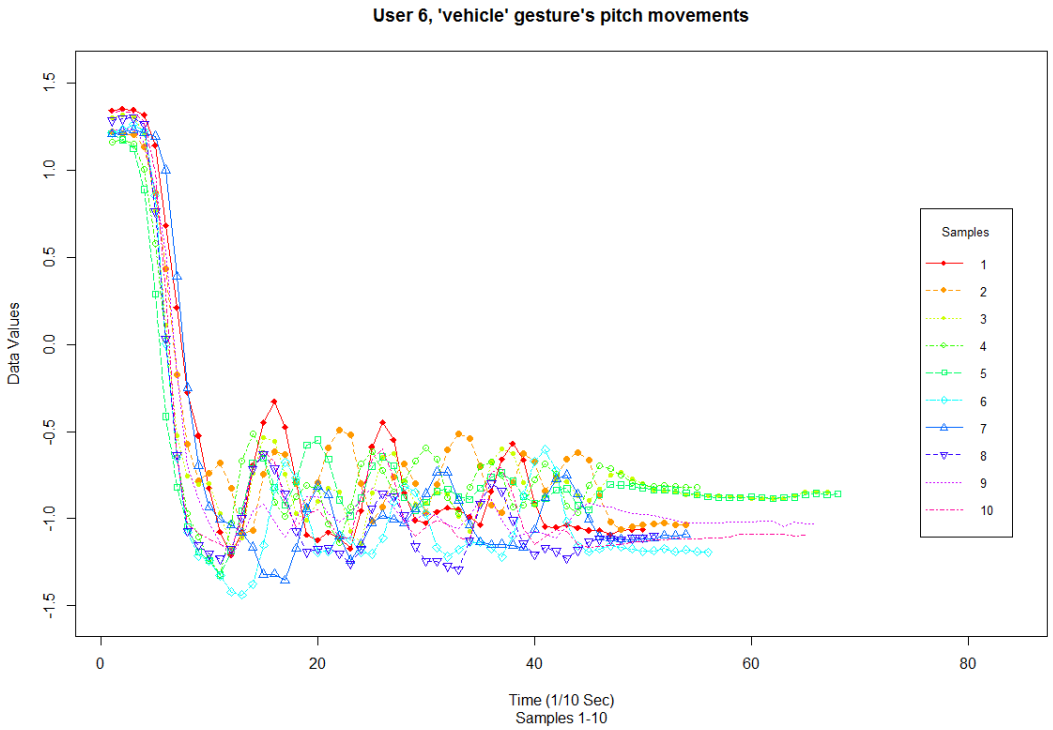

Fig. A-30 Vehicle gesture, pitch feature, user 06. All samples exhibit reversed movement.

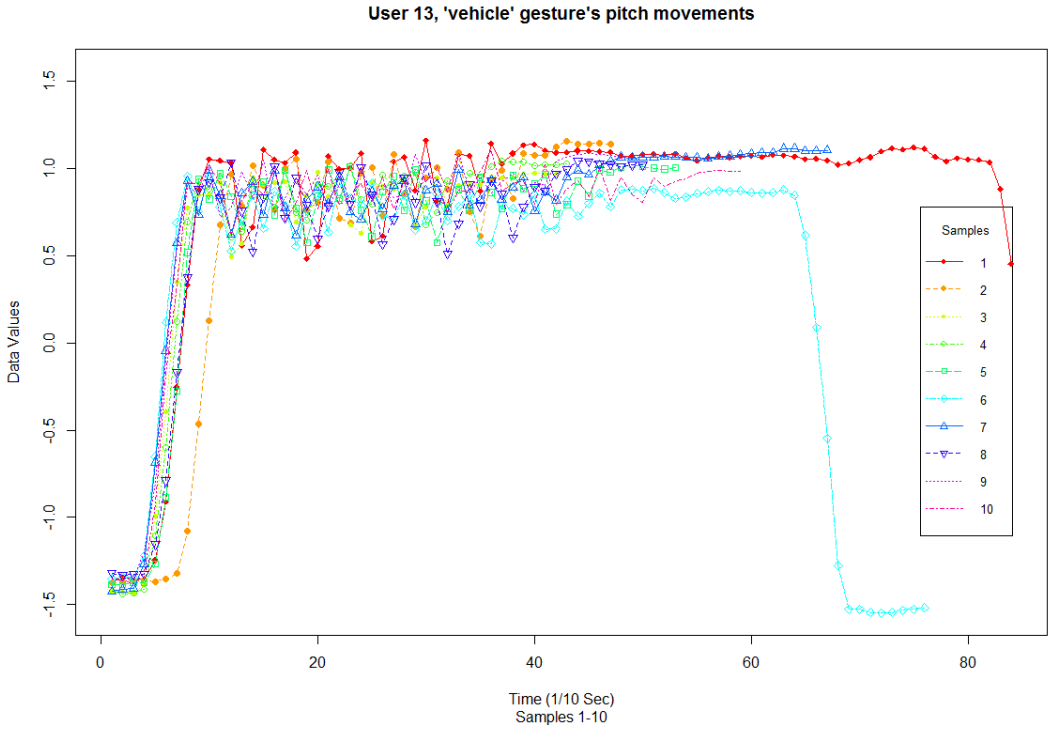

Fig. A-31 Vehicle gesture, pitch feature, user 13. Sample 01 and 06 exhibit unusual movement at the end.

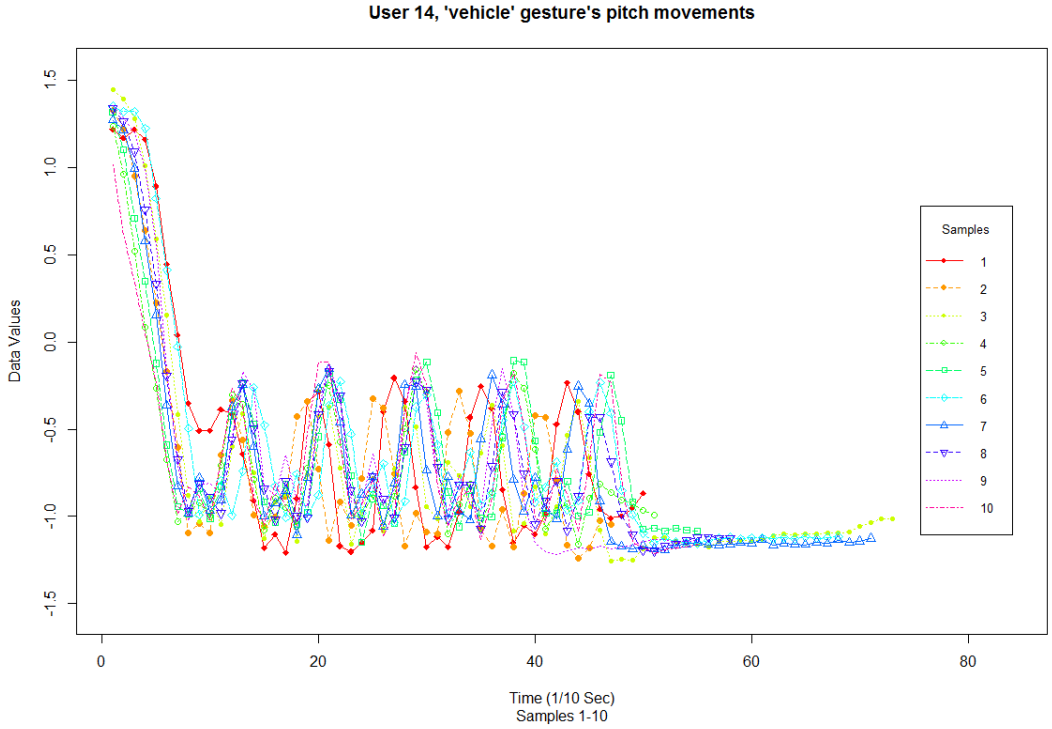

Fig. A-32 Vehicle gesture, pitch feature, user 14. All samples exhibit reversed movement.

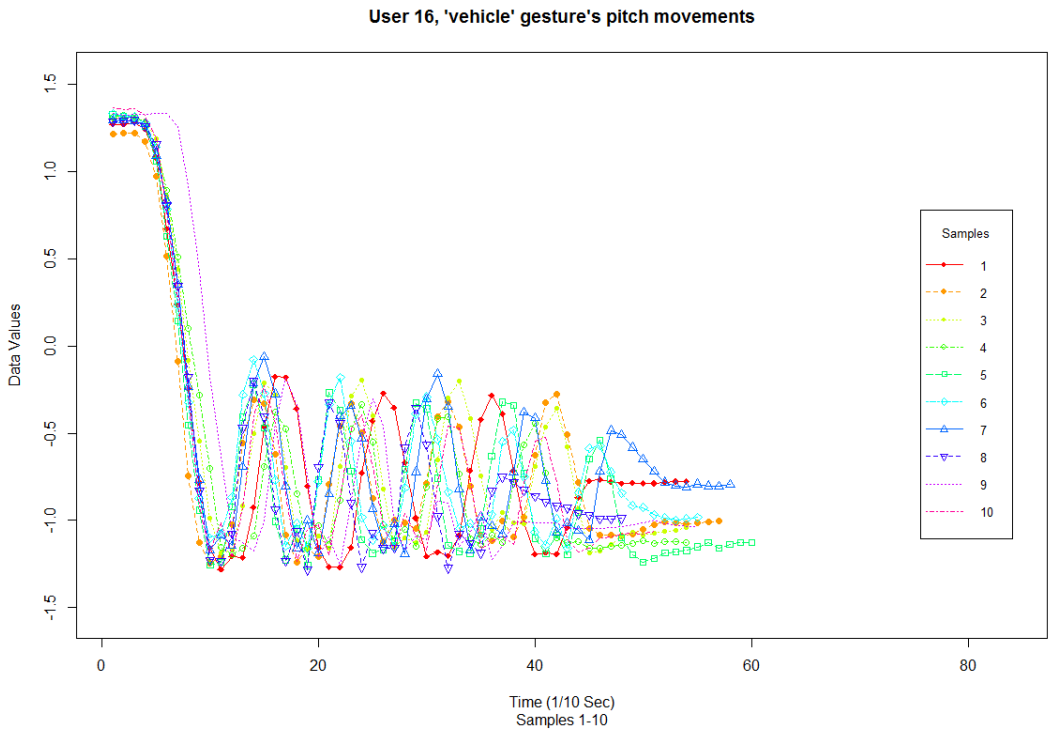

Fig. A-33 Vehicle gesture, pitch feature, user 16. All samples exhibit reversed movement.

Appendix B. Charts Exhibiting Unusual xAcc Behavior

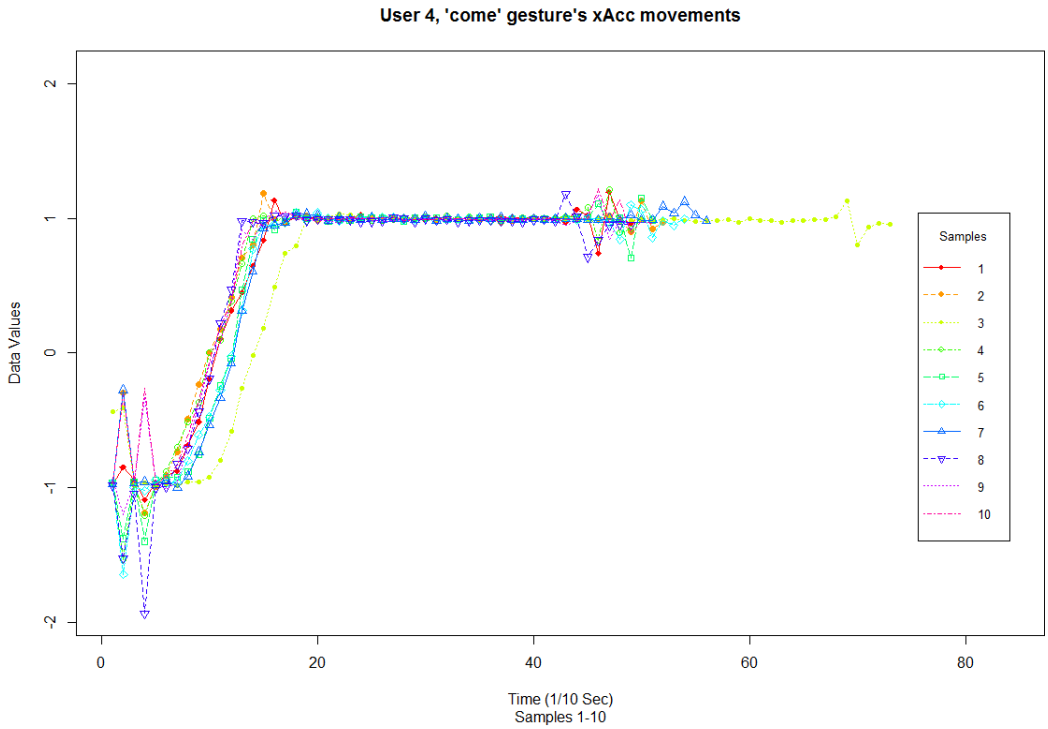

Fig. B-1 Come gesture, xAcc feature, user 04. All samples exhibit reversed movement.

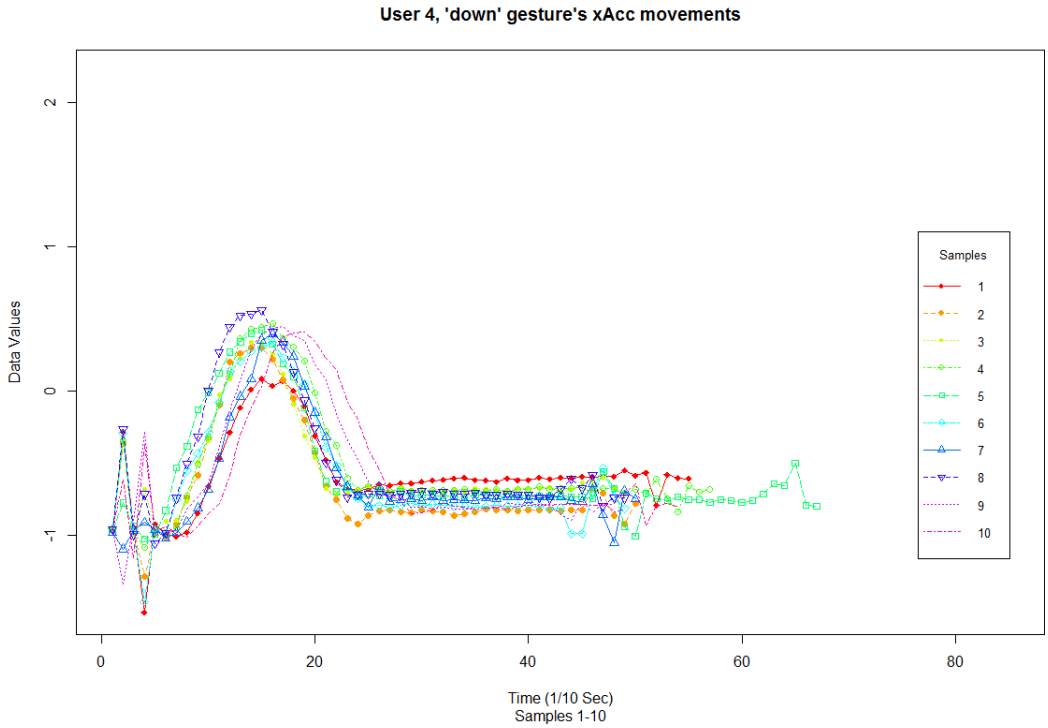

Fig. B-2 Down gesture, xAcc feature, user 04. All samples exhibit reversed movement.

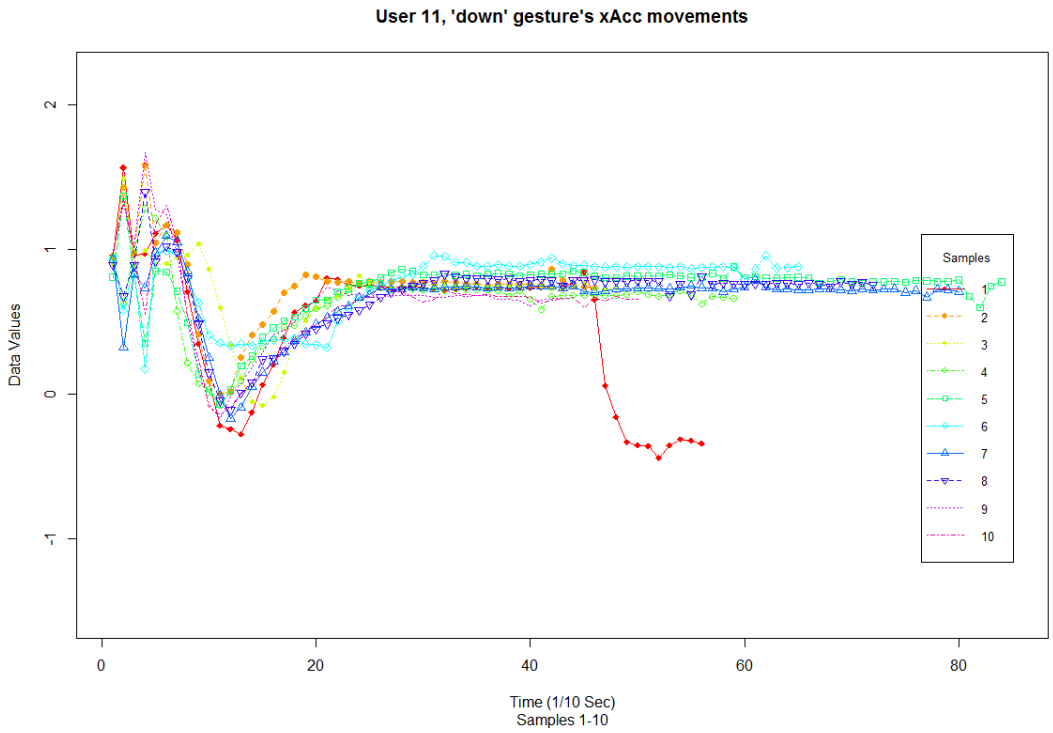

Fig. B-3 Down gesture, xAcc feature, user 11. Sample 01 exhibit unusual movement at the end.

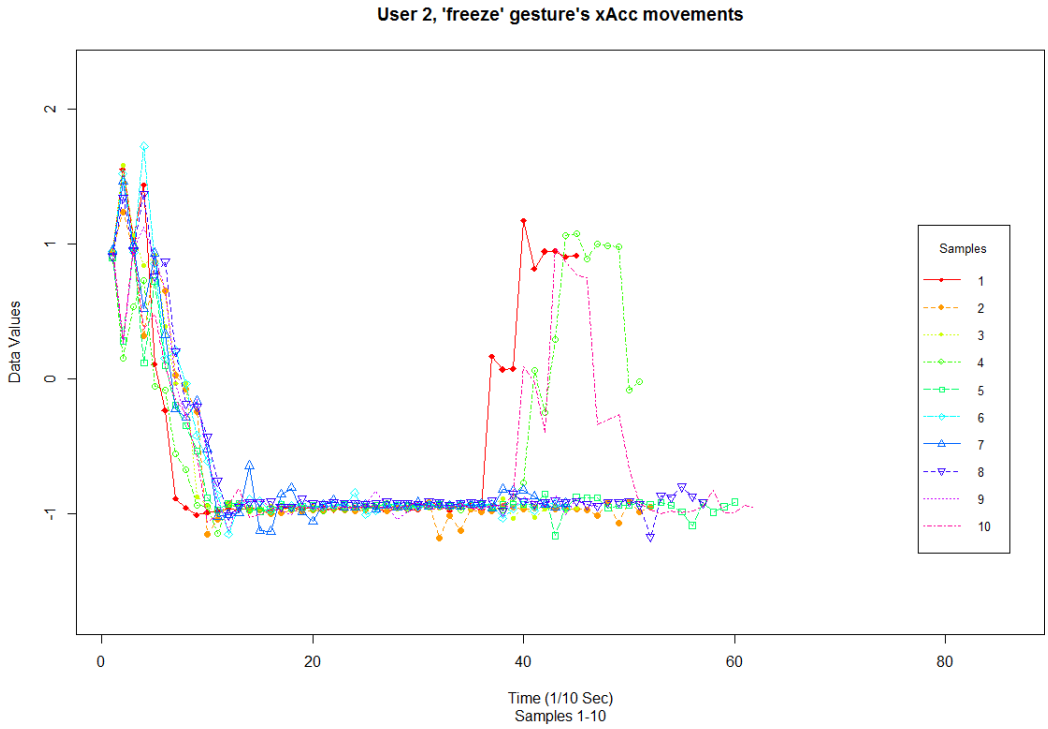

Fig. B-4 Freeze gesture, xAcc feature, user 02. Sample 01 and 04 exhibit unusual movement at the end.

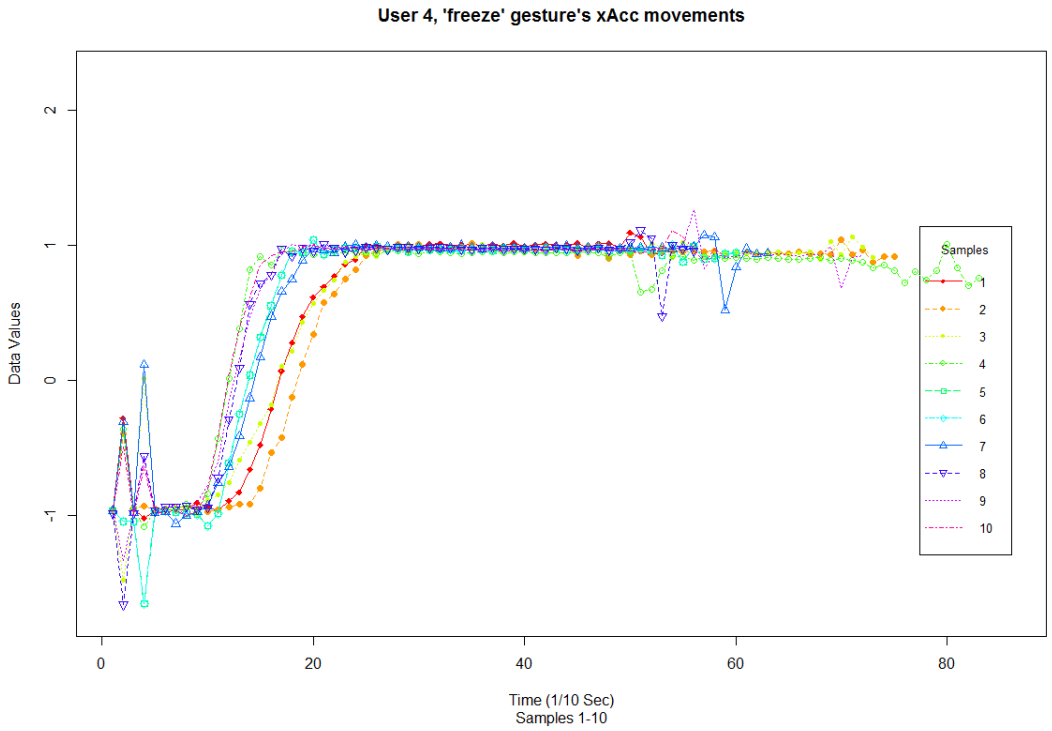

Fig. B-5 Freeze gesture, xAcc feature, user 04. All samples exhibit reversed movement.

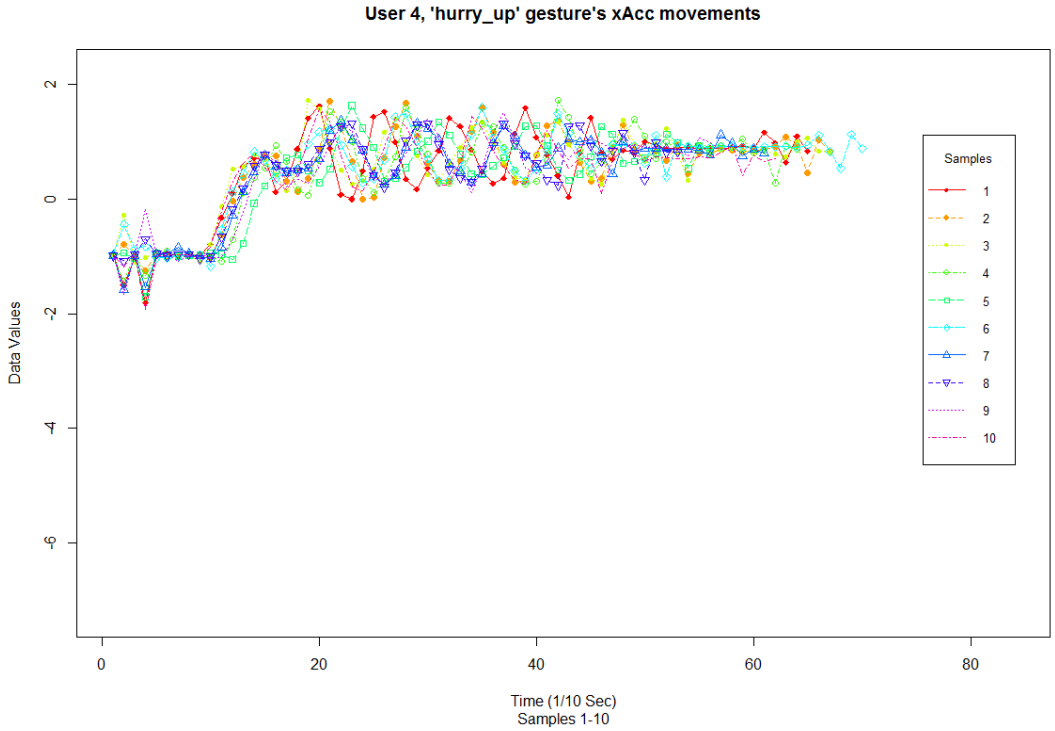

Fig. B-6 Hurry up gesture, xAcc feature, user 04. All samples exhibit reversed movement.

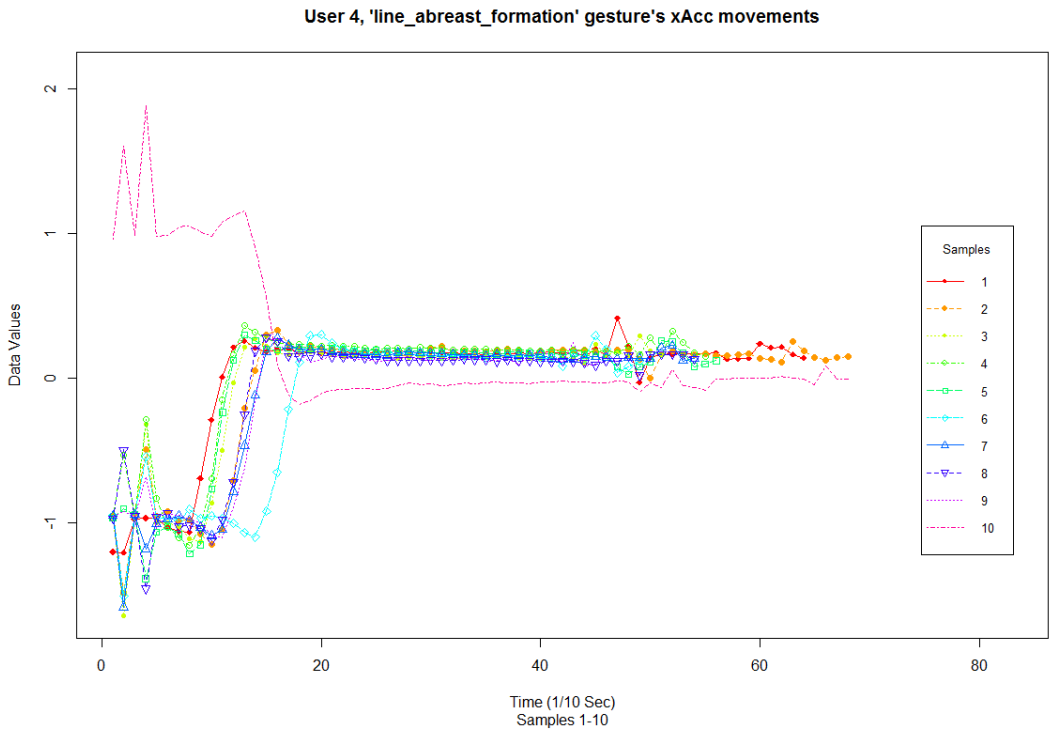

Fig. B-7 Line abreast formation gesture, xAcc feature, user 04. Samples 01-09 exhibit reversed movement.

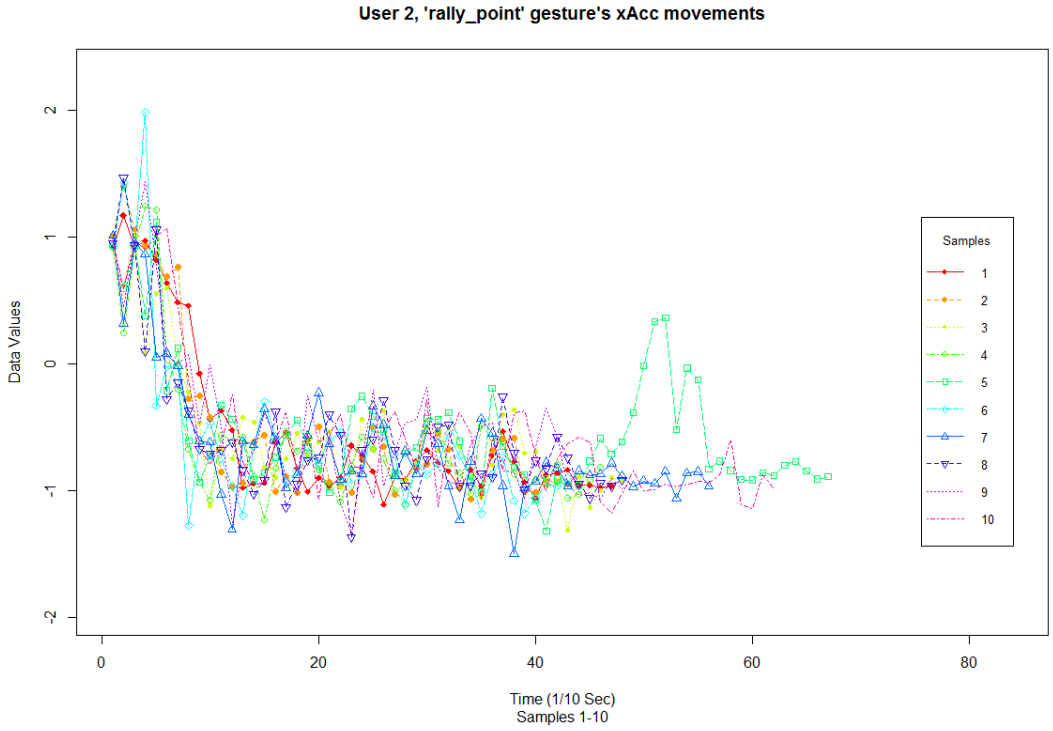

Fig. B-8 Rally point gesture, xAcc feature, user 02. Sample 05 exhibit unusual movement at the end.

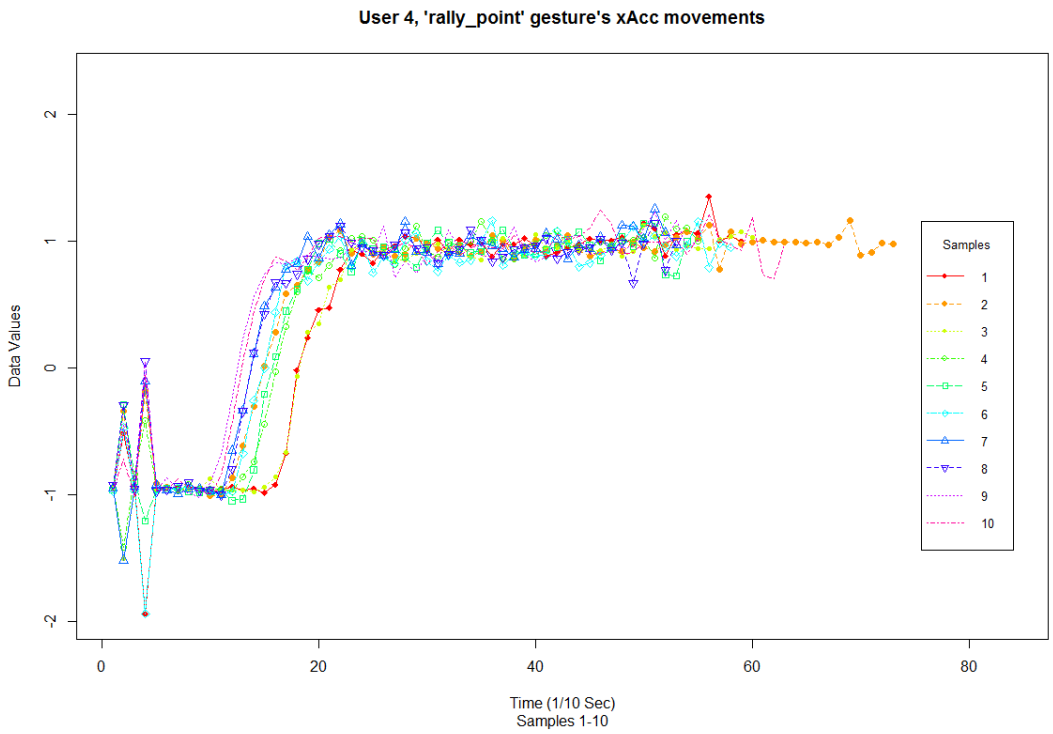

Fig. B-9 Rally point gesture, xAcc feature, user 04. All samples exhibit reversed movement.

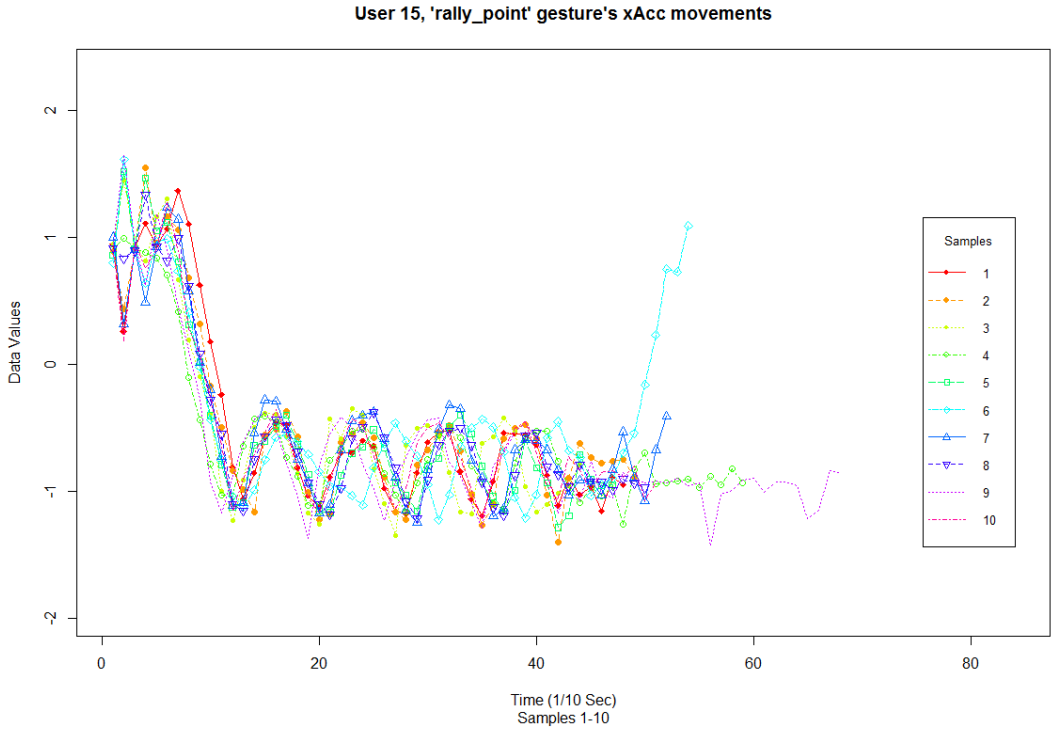

Fig. B-10 Rally point gesture, xAcc feature, user 15. Sample 06 exhibit unusual movement at the end.

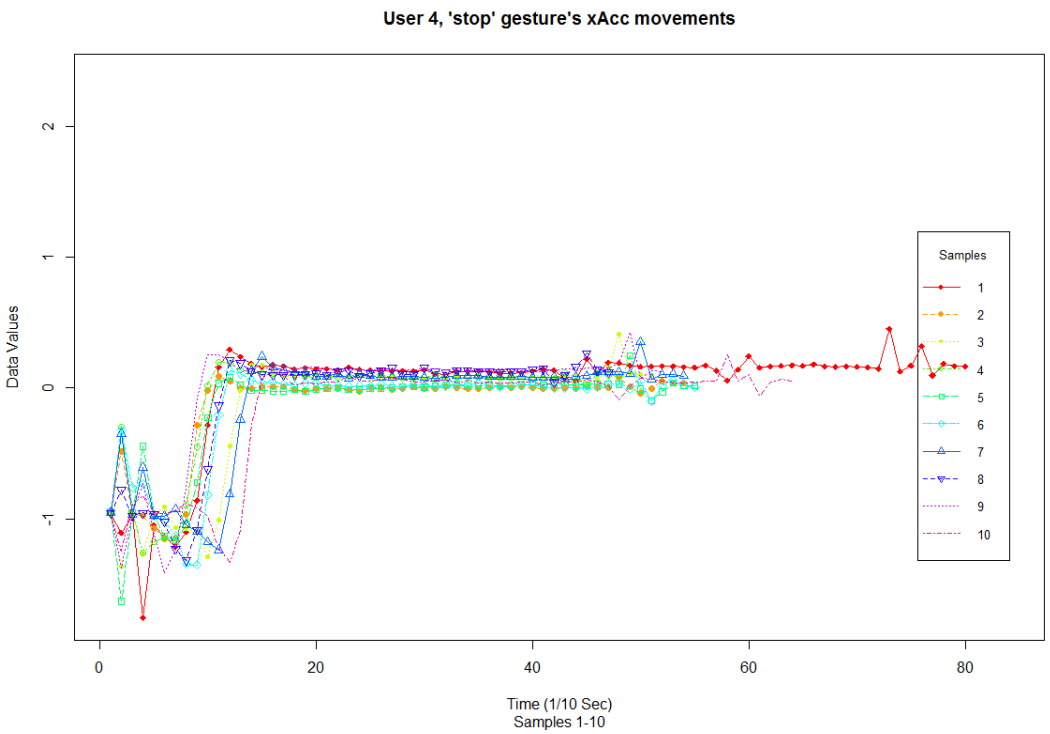

Fig. B-11 Stop gesture, xAcc feature, user 04. All samples exhibit reversed movement.

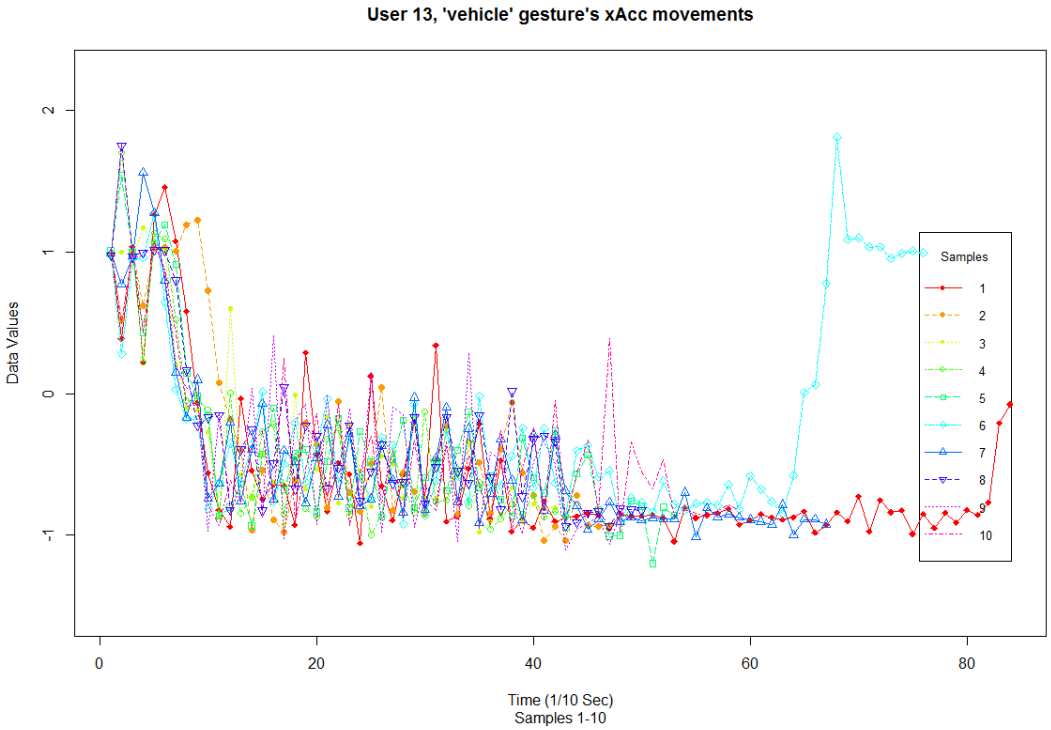

Fig. B-12 Vehicle gesture, xAcc feature, user 13. Sample 01 and 06 exhibit unusual movement at the end.

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Appendix C. Unusual Samples Categorized by Gesture

Come

User 04 - come - 01 [Exhibit reversed xAcc movement]
User 04 - come - 02 [Exhibit reversed xAcc movement]
User 04 - come - 03 [Exhibit reversed xAcc movement]
User 04 - come - 04 [Exhibit reversed xAcc movement]
User 04 - come - 05 [Exhibit reversed xAcc movement]
User 04 - come - 06 [Exhibit reversed xAcc movement]
User 04 - come - 07 [Exhibit reversed xAcc movement]
User 04 - come - 08 [Exhibit reversed xAcc movement]
User 04 - come - 09 [Exhibit reversed xAcc movement]
User 04 - come - 10 [Exhibit reversed xAcc movement]

User 06 - come - 01 [Exhibit reversed Pitch movement]
User 06 - come - 02 [Exhibit reversed Pitch movement]
User 06 - come - 03 [Exhibit reversed Pitch movement]
User 06 - come - 04 [Exhibit reversed Pitch movement]
User 06 - come - 05 [Exhibit reversed Pitch movement]
User 06 - come - 06 [Exhibit reversed Pitch movement]
User 06 - come - 07 [Exhibit reversed Pitch movement]
User 06 - come - 08 [Exhibit reversed Pitch movement]
User 06 - come - 09 [Exhibit reversed Pitch movement]
User 06 - come - 10 [Exhibit reversed Pitch movement]

User 14 - come – 01 [Exhibit reversed Pitch movement]
User 14 - come – 02 [Exhibit reversed Pitch movement]
User 14 - come – 03 [Exhibit reversed Pitch movement]
User 14 - come – 04 [Exhibit reversed Pitch movement]
User 14 - come – 05 [Exhibit reversed Pitch movement]
User 14 - come – 06 [Exhibit reversed Pitch movement]
User 14 - come – 07 [Exhibit reversed Pitch movement]
User 14 - come – 08 [Exhibit reversed Pitch movement]
User 14 - come – 09 [Exhibit reversed Pitch movement]
User 14 - come – 10 [Exhibit reversed Pitch movement]

User 16 - come - 01 [Exhibit reversed Pitch movement]
User 16 - come - 02 [Exhibit reversed Pitch movement]
User 16 - come - 03 [Exhibit reversed Pitch movement]
User 16 - come - 04 [Exhibit reversed Pitch movement]
User 16 - come - 05 [Exhibit reversed Pitch movement]
User 16 - come - 06 [Exhibit reversed Pitch movement]
User 16 - come - 07 [Exhibit reversed Pitch movement]
User 16 - come - 08 [Exhibit reversed Pitch movement]
User 16 - come - 09 [Exhibit reversed Pitch movement]
User 16 - come - 10 [Exhibit reversed Pitch movement]

Down

User 02 - down - 10 [Exhibit unusual Pitch movement at the end]

User 04 - down - 01 [Exhibit reversed xAcc movement]
User 04 - down - 02 [Exhibit reversed xAcc movement]
User 04 - down - 03 [Exhibit reversed xAcc movement]
User 04 - down - 04 [Exhibit reversed xAcc movement]
User 04 - down - 05 [Exhibit reversed xAcc movement]
User 04 - down - 06 [Exhibit reversed xAcc movement]
User 04 - down - 07 [Exhibit reversed xAcc movement]
User 04 - down - 08 [Exhibit reversed xAcc movement]
User 04 - down - 09 [Exhibit reversed xAcc movement]
User 04 - down - 10 [Exhibit reversed xAcc movement]

User 06 - down - 01 [Exhibit reversed Pitch movement]
User 06 - down - 02 [Exhibit reversed Pitch movement]
User 06 - down - 03 [Exhibit reversed Pitch movement]
User 06 - down - 04 [Exhibit reversed Pitch movement]
User 06 - down - 05 [Exhibit reversed Pitch movement]
User 06 - down - 06 [Exhibit reversed Pitch movement]
User 06 - down - 07 [Exhibit reversed Pitch movement]
User 06 - down - 08 [Exhibit reversed Pitch movement]
User 06 - down - 09 [Exhibit reversed Pitch movement]
User 06 - down - 10 [Exhibit reversed Pitch movement]

User 11 - down - 01 [Exhibit unusual Pitch and xACC movement at the end]

User 14 - down - 01 [Exhibit reversed Pitch movement]
User 14 - down - 02 [Exhibit reversed Pitch movement]
User 14 - down - 03 [Exhibit reversed Pitch movement]
User 14 - down - 04 [Exhibit reversed Pitch movement]
User 14 - down - 05 [Exhibit reversed Pitch movement]
User 14 - down - 06 [Exhibit reversed Pitch movement]
User 14 - down - 07 [Exhibit reversed Pitch movement]
User 14 - down - 08 [Exhibit reversed Pitch movement]
User 14 - down - 09 [Exhibit reversed Pitch movement]
User 14 - down - 10 [Exhibit reversed Pitch movement]

User 15 - down - 08 [Exhibit unusual Pitch movement at the end]

User 16 - down - 01 [Exhibit reversed Pitch movement]
User 16 - down - 02 [Exhibit reversed Pitch movement]
User 16 - down - 03 [Exhibit reversed Pitch movement]
User 16 - down - 04 [Exhibit reversed Pitch movement]
User 16 - down - 05 [Exhibit reversed Pitch movement]
User 16 - down - 06 [Exhibit reversed Pitch movement]

User 16 - down - 07 [Exhibit reversed Pitch movement]
User 16 - down - 08 [Exhibit reversed Pitch movement]
User 16 - down - 09 [Exhibit reversed Pitch movement]
User 16 - down - 10 [Exhibit reversed Pitch movement]

Freeze

User 02 - freeze - 01 [Exhibit reversed Pitch movement and unusual xAcc movement at the end]
User 02 - freeze - 02 [Exhibit reversed Pitch movement]
User 02 - freeze - 03 [Exhibit reversed Pitch movement]
User 02 - freeze - 04 [Exhibit reversed Pitch movement and unusual xAcc movement at the end]
User 02 - freeze - 05 [Exhibit reversed Pitch movement]
User 02 - freeze - 06 [Exhibit reversed Pitch movement]
User 02 - freeze - 07 [Exhibit reversed Pitch movement]
User 02 - freeze - 08 [Exhibit reversed Pitch movement]
User 02 - freeze - 09 [Exhibit reversed Pitch movement]
User 02 - freeze - 10 [Exhibit reversed Pitch movement]

User 04 - freeze - 01 [Exhibit reversed xAcc movement]
User 04 - freeze - 02 [Exhibit reversed xAcc movement]
User 04 - freeze - 03 [Exhibit reversed xAcc movement]
User 04 - freeze - 04 [Exhibit reversed xAcc movement]
User 04 - freeze - 05 [Exhibit reversed xAcc movement]
User 04 - freeze - 06 [Exhibit reversed xAcc movement]
User 04 - freeze - 07 [Exhibit reversed xAcc movement]
User 04 - freeze - 08 [Exhibit reversed xAcc movement]
User 04 - freeze - 09 [Exhibit reversed xAcc movement]
User 04 - freeze - 10 [Exhibit reversed xAcc movement]

User 06 - freeze - 01 [Exhibit reversed Pitch movement]
User 06 - freeze - 02 [Exhibit reversed Pitch movement]
User 06 - freeze - 03 [Exhibit reversed Pitch movement]
User 06 - freeze - 04 [Exhibit reversed Pitch movement]
User 06 - freeze - 05 [Exhibit reversed Pitch movement]
User 06 - freeze - 06 [Exhibit reversed Pitch movement]
User 06 - freeze - 07 [Exhibit reversed Pitch movement]
User 06 - freeze - 08 [Exhibit reversed Pitch movement]
User 06 - freeze - 09 [Exhibit reversed Pitch movement]
User 06 - freeze - 10 [Exhibit reversed Pitch movement]

User 14 - freeze - 01 [Exhibit reversed Pitch movement]
User 14 - freeze - 02 [Exhibit reversed Pitch movement]
User 14 - freeze - 03 [Exhibit reversed Pitch movement]
User 14 - freeze - 04 [Exhibit reversed Pitch movement]
User 14 - freeze - 05 [Exhibit reversed Pitch movement]

User 14 - freeze - 06 [Exhibit reversed Pitch movement]
User 14 - freeze - 07 [Exhibit reversed Pitch movement]
User 14 - freeze - 08 [Exhibit reversed Pitch movement]
User 14 - freeze - 09 [Exhibit reversed Pitch movement]
User 14 - freeze - 10 [Exhibit reversed Pitch movement]

User 16 - freeze - 01 [Exhibit reversed Pitch movement]
User 16 - freeze - 02 [Exhibit reversed Pitch movement]
User 16 - freeze - 03 [Exhibit reversed Pitch movement]
User 16 - freeze - 04 [Exhibit reversed Pitch movement]
User 16 - freeze - 05 [Exhibit reversed Pitch movement]
User 16 - freeze - 06 [Exhibit reversed Pitch movement]
User 16 - freeze - 07 [Exhibit reversed Pitch movement]
User 16 - freeze - 08 [Exhibit reversed Pitch movement]
User 16 - freeze - 09 [Exhibit reversed Pitch movement]
User 16 - freeze - 10 [Exhibit reversed Pitch movement]

Hurry Up

User 02 - hurry_up - 01 [Exhibit reversed Pitch movement]
User 02 - hurry_up - 02 [Exhibit reversed Pitch movement]
User 02 - hurry_up - 03 [Exhibit reversed Pitch movement]
User 02 - hurry_up - 04 [Exhibit reversed Pitch movement]
User 02 - hurry_up - 05 [Exhibit reversed Pitch movement]

User 04 - hurry_up - 01 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 02 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 03 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 04 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 05 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 06 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 07 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 08 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 09 [Exhibit reversed xAcc movement]
User 04 - hurry_up - 10 [Exhibit reversed xAcc movement]

User 06 - hurry_up - 01 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 02 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 03 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 04 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 05 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 06 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 07 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 08 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 09 [Exhibit reversed Pitch movement]
User 06 - hurry_up - 10 [Exhibit reversed Pitch movement]

User 10 - hurry_up - 06 [Exhibit unusual Pitch movement at the end]
User 10 - hurry_up - 08 [Exhibit unusual Pitch movement at the end]

User 14 - hurry_up - 01 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 02 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 03 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 04 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 05 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 06 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 07 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 08 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 09 [Exhibit reversed Pitch movement]
User 14 - hurry_up - 10 [Exhibit reversed Pitch movement]

User 16 - hurry_up - 01 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 02 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 03 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 04 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 05 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 06 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 07 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 08 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 09 [Exhibit reversed Pitch movement]
User 16 - hurry_up - 10 [Exhibit reversed Pitch movement]

Line Abreast Formation

User 04 - line_abreast_formation - 01 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 02 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 03 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 04 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 05 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 06 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 07 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 08 [Exhibit reversed xAcc movement]
User 04 - line_abreast_formation - 09 [Exhibit reversed xAcc movement]

User 06 - line_abreast_formation - 01 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 02 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 03 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 04 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 05 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 06 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 07 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 08 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 09 [Exhibit reversed Pitch movement]
User 06 - line_abreast_formation - 10 [Exhibit reversed Pitch movement]

User 14 - line_abreast_formation - 01 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 02 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 03 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 04 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 05 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 06 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 07 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 08 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 09 [Exhibit reversed Pitch movement]
User 14 - line_abreast_formation - 10 [Exhibit reversed Pitch movement]

User 16 - line_abreast_formation - 01 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 02 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 03 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 04 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 05 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 06 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 07 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 08 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 09 [Exhibit reversed Pitch movement]
User 16 - line_abreast_formation - 10 [Exhibit reversed Pitch movement]

Rally Point

User 02 - rally_point - 01 [Exhibit reversed Pitch movement]
User 02 - rally_point - 02 [Exhibit reversed Pitch movement]
User 02 - rally_point - 03 [Exhibit reversed Pitch movement]
User 02 - rally_point - 04 [Exhibit reversed Pitch movement]
User 02 - rally_point - 05 [Exhibit reversed Pitch movement and unusual xAcc movement]
User 02 - rally_point - 06 [Exhibit reversed Pitch movement]
User 02 - rally_point - 07 [Exhibit reversed Pitch movement]
User 02 - rally_point - 08 [Exhibit reversed Pitch movement]
User 02 - rally_point - 09 [Exhibit reversed Pitch movement]
User 02 - rally_point - 10 [Exhibit reversed Pitch movement]

User 04 - rally_point - 01 [Exhibit reversed xAcc movement]
User 04 - rally_point - 02 [Exhibit reversed xAcc movement]
User 04 - rally_point - 03 [Exhibit reversed xAcc movement]
User 04 - rally_point - 04 [Exhibit reversed xAcc movement]
User 04 - rally_point - 05 [Exhibit reversed xAcc movement]
User 04 - rally_point - 06 [Exhibit reversed xAcc movement]
User 04 - rally_point - 07 [Exhibit reversed xAcc movement]
User 04 - rally_point - 08 [Exhibit reversed xAcc movement]
User 04 - rally_point - 09 [Exhibit reversed xAcc movement]
User 04 - rally_point - 10 [Exhibit reversed xAcc movement]

User 06 - rally_point - 01 [Exhibit reversed Pitch movement]
User 06 - rally_point - 02 [Exhibit reversed Pitch movement]
User 06 - rally_point - 03 [Exhibit reversed Pitch movement]
User 06 - rally_point - 04 [Exhibit reversed Pitch movement]
User 06 - rally_point - 05 [Exhibit reversed Pitch movement]
User 06 - rally_point - 06 [Exhibit reversed Pitch movement]
User 06 - rally_point - 07 [Exhibit reversed Pitch movement]
User 06 - rally_point - 08 [Exhibit reversed Pitch movement]
User 06 - rally_point - 09 [Exhibit reversed Pitch movement]
User 06 - rally_point - 10 [Exhibit reversed Pitch movement]

User 14 - rally_point - 01 [Exhibit reversed Pitch movement]
User 14 - rally_point - 02 [Exhibit reversed Pitch movement]
User 14 - rally_point - 03 [Exhibit reversed Pitch movement]
User 14 - rally_point - 04 [Exhibit reversed Pitch movement]
User 14 - rally_point - 05 [Exhibit reversed Pitch movement]
User 14 - rally_point - 06 [Exhibit reversed Pitch movement]
User 14 - rally_point - 07 [Exhibit reversed Pitch movement]
User 14 - rally_point - 08 [Exhibit reversed Pitch movement]
User 14 - rally_point - 09 [Exhibit reversed Pitch movement]
User 14 - rally_point - 10 [Exhibit reversed Pitch movement]

User 15 - rally_point - 06 [Exhibit unusual Pitch and xAcc movement at the end]

User 16 - rally_point - 01 [Exhibit reversed Pitch movement]
User 16 - rally_point - 02 [Exhibit reversed Pitch movement]
User 16 - rally_point - 03 [Exhibit reversed Pitch movement]
User 16 - rally_point - 04 [Exhibit reversed Pitch movement]
User 16 - rally_point - 05 [Exhibit reversed Pitch movement]
User 16 - rally_point - 06 [Exhibit reversed Pitch movement]
User 16 - rally_point - 07 [Exhibit reversed Pitch movement]
User 16 - rally_point - 08 [Exhibit reversed Pitch movement]
User 16 - rally_point - 09 [Exhibit reversed Pitch movement]
User 16 - rally_point - 10 [Exhibit reversed Pitch movement]

Stop

User 04 - stop - 01 [Exhibit reversed xAcc movement]
User 04 - stop - 02 [Exhibit reversed xAcc movement]
User 04 - stop - 03 [Exhibit reversed xAcc movement]
User 04 - stop - 04 [Exhibit reversed xAcc movement]
User 04 - stop - 05 [Exhibit reversed xAcc movement]
User 04 - stop - 06 [Exhibit reversed xAcc movement]
User 04 - stop - 07 [Exhibit reversed xAcc movement]
User 04 - stop - 08 [Exhibit reversed xAcc movement]

User 04 - stop - 09 [Exhibit reversed xAcc movement]
User 04 - stop - 10 [Exhibit reversed xAcc movement]

User 06 - stop - 01 [Exhibit reversed Pitch movement]
User 06 - stop - 02 [Exhibit reversed Pitch movement]
User 06 - stop - 03 [Exhibit reversed Pitch movement]
User 06 - stop - 04 [Exhibit reversed Pitch movement]
User 06 - stop - 05 [Exhibit reversed Pitch movement]
User 06 - stop - 06 [Exhibit reversed Pitch movement]
User 06 - stop - 07 [Exhibit reversed Pitch movement]
User 06 - stop - 08 [Exhibit reversed Pitch movement]
User 06 - stop - 09 [Exhibit reversed Pitch movement]
User 06 - stop - 10 [Exhibit reversed Pitch movement]

User 14 - stop - 01 [Exhibit reversed Pitch movement]
User 14 - stop - 02 [Exhibit reversed Pitch movement]
User 14 - stop - 03 [Exhibit reversed Pitch movement]
User 14 - stop - 04 [Exhibit reversed Pitch movement]
User 14 - stop - 05 [Exhibit reversed Pitch movement]
User 14 - stop - 06 [Exhibit reversed Pitch movement]
User 14 - stop - 07 [Exhibit reversed Pitch movement]
User 14 - stop - 08 [Exhibit reversed Pitch movement]
User 14 - stop - 09 [Exhibit reversed Pitch movement]
User 14 - stop - 10 [Exhibit reversed Pitch movement]

User 16 - stop - 01 [Exhibit reversed Pitch movement]
User 16 - stop - 02 [Exhibit reversed Pitch movement]
User 16 - stop - 03 [Exhibit reversed Pitch movement]
User 16 - stop - 04 [Exhibit reversed Pitch movement]
User 16 - stop - 05 [Exhibit reversed Pitch movement]
User 16 - stop - 06 [Exhibit reversed Pitch movement]
User 16 - stop - 07 [Exhibit reversed Pitch movement]
User 16 - stop - 08 [Exhibit reversed Pitch movement]
User 16 - stop - 09 [Exhibit reversed Pitch movement]
User 16 - stop - 10 [Exhibit reversed Pitch movement]

Vehicle

User 06 - vehicle - 01 [Exhibit reversed Pitch movement]
User 06 - vehicle - 02 [Exhibit reversed Pitch movement]
User 06 - vehicle - 03 [Exhibit reversed Pitch movement]
User 06 - vehicle - 04 [Exhibit reversed Pitch movement]
User 06 - vehicle - 05 [Exhibit reversed Pitch movement]
User 06 - vehicle - 06 [Exhibit reversed Pitch movement]
User 06 - vehicle - 07 [Exhibit reversed Pitch movement]
User 06 - vehicle - 08 [Exhibit reversed Pitch movement]

User 06 - vehicle - 09 [Exhibit reversed Pitch movement]
User 06 - vehicle - 10 [Exhibit reversed Pitch movement]

User 13 - vehicle - 01 [Exhibit unusual Pitch and xAcc movement at the end]
User 13 - vehicle - 06 [Exhibit unusual Pitch and xAcc movement at the end]

User 14 - vehicle - 01 [Exhibit reversed Pitch movement]
User 14 - vehicle - 02 [Exhibit reversed Pitch movement]
User 14 - vehicle - 03 [Exhibit reversed Pitch movement]
User 14 - vehicle - 04 [Exhibit reversed Pitch movement]
User 14 - vehicle - 05 [Exhibit reversed Pitch movement]
User 14 - vehicle - 06 [Exhibit reversed Pitch movement]
User 14 - vehicle - 07 [Exhibit reversed Pitch movement]
User 14 - vehicle - 08 [Exhibit reversed Pitch movement]
User 14 - vehicle - 09 [Exhibit reversed Pitch movement]
User 14 - vehicle - 10 [Exhibit reversed Pitch movement]

User 16 - vehicle - 01 [Exhibit reversed Pitch movement]
User 16 - vehicle - 02 [Exhibit reversed Pitch movement]
User 16 - vehicle - 03 [Exhibit reversed Pitch movement]
User 16 - vehicle - 04 [Exhibit reversed Pitch movement]
User 16 - vehicle - 05 [Exhibit reversed Pitch movement]
User 16 - vehicle - 06 [Exhibit reversed Pitch movement]
User 16 - vehicle - 07 [Exhibit reversed Pitch movement]
User 16 - vehicle - 08 [Exhibit reversed Pitch movement]
User 16 - vehicle - 09 [Exhibit reversed Pitch movement]
User 16 - vehicle - 10 [Exhibit reversed Pitch movement]

1 (PDF) DEFENSE TECHNICAL INFORMATION CTR DTIC OCA

2 (PDF) DIRECTOR US ARMY RESEARCH LAB RDRL CIO L IMAL HRA MAIL & RECORDS MGMT

1 (PDF) GOVT PRINTG OFC A MALHOTRA

5 (PDF) DIRECTOR US ARMY RESEARCH LAB RDRL CII B STEPHEN M RUSSELL ROBERT P WINKLER ANDRE V HARRISON MICHAEL H LEE RDRL CII DEBORAH A WELSH

INTENTIONALLY LEFT BLANK.