Eye Movement Classification with K-Means

Extended to Smooth Pursuit

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Introduction:

- Clustering is a machine learning approach to dividing data points into groups.
- K-Means is a clustering algorithm that allows which allows a user to specify the exact number of grouping which should exist in the data.
- Eye Movement Classification is fundamentally a problem of grouping data points by similarity, which suggest clustering is an effective approach.

Algorithm:

Remove Outliers:

1. Calculate velocity for every datapoint as the geometric mean of x and y velocities.
2. Calculate acceleration for every data point as the absolute difference of consecutive velocities.
3. Calculate a moving median across all data points.
4. Mark points which are 3 or more local median absolute deviations away from median as Noise.

Cluster Points with 3-Means:

1. Initialize 3 random cluster centers.
2. Assign each point to its closest cluster center.
3. Adjust the cluster centers as the mean of all points assigned to the cluster.
4. Repeat steps 2 and 3 until stability is reached.

Associate Clusters with Movements Based on Mean Cluster Velocity:

1. Calculate the mean velocity for each of the 3 clusters.
2. Assign movements for each point as:
   a. Slowest -> Fixation
   b. Middle -> Pursuit
   c. Fastest -> Saccade

Pseudo Code:

```
Given set of data points s={s_1,...,s_n}
Randomly initialize set c={c_1,...,c_k} of k centroids
Initialize a set of results r={r_1,...,r_n} to zeros

Loop until c does not change:
  for i = 1 to n:
    min_cluster = 0
    min_distance = MAX_FLOAT
    for j = 1 to k:
      calculate distance(s_i, c_j)
      if (distance < min_distance):
        min_cluster = j
        min_distance = distance
    r_i = min_cluster

  for i = 1 to k:
    calculate the centroid of each cluster i
    set c_i = to centroid i

Return sets c and r.  R is the cluster for each point in s, and c is the centroid of each cluster.
```

Differences:

IVVT:

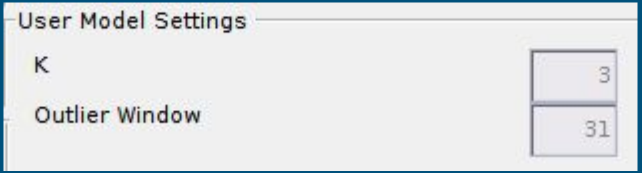
- Relies only on velocity.
- Compares values to user-defined thresholds.
- Uses validity for noise detection.

K-Means:

- Uses velocity and acceleration.
- Learns divisions from data.
- Uses moving median for noise detection.

Parameters:

- **K**: the number of clusters to detect in the data. 3 was used in this project and any other value would not be valid for 3 behavior classification.
- **Outlier Window**: the width of the window used to calculate the local median for outlier detection. 31 was used in this project. Much larger values (>100) and much smaller values (<10) do not work but behavior does not change much inside of that range.



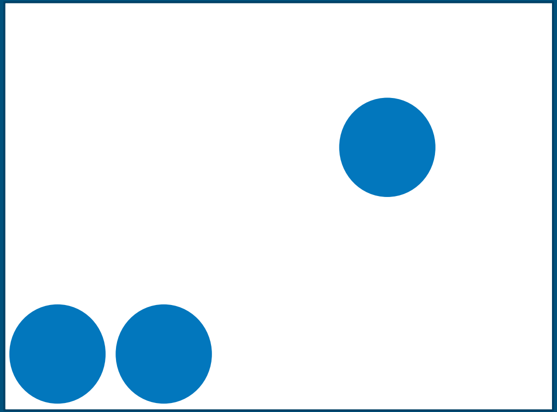
Challenges:

- K-means is very noise sensitive. Early implementations would often create single-point clusters for very high velocity and acceleration points.
- Very positive values and very negative velocity and acceleration values actually belong in the same cluster.
- The clusters are not as crisp as I'd hoped.
- K-Means is non-deterministic. Occasionally a run will produce unusual results.

Visualizing Velocity and Acceleration:

Acceleration

Ideal Values



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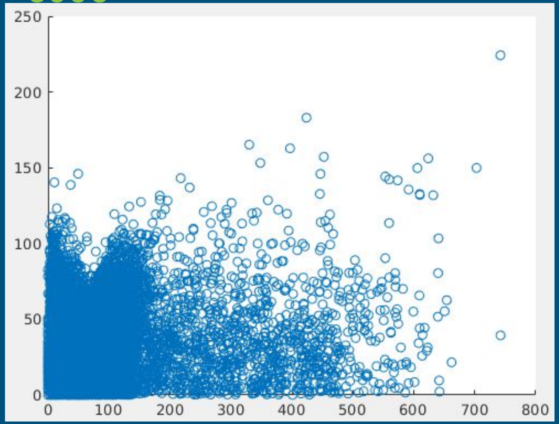

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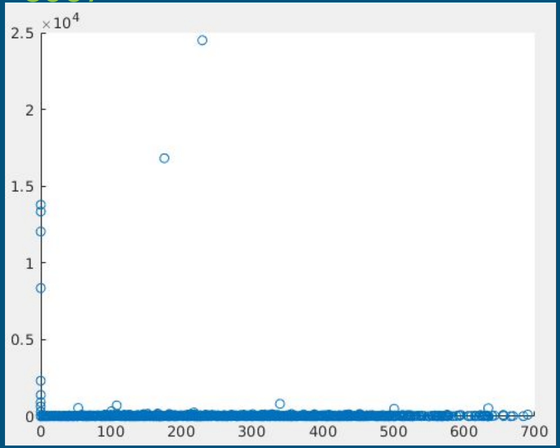

Velocity

Scores:

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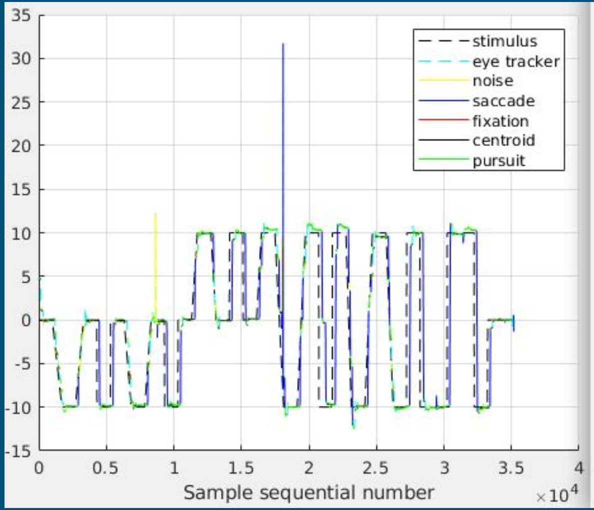
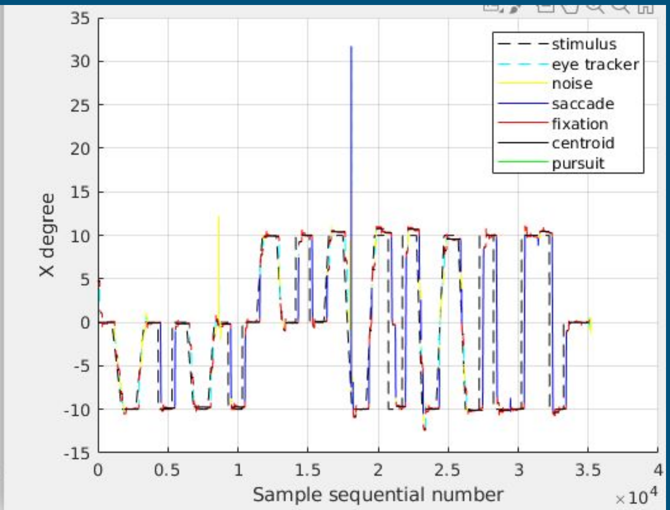
	SQnS	FQnS	PQnS	MisFix	FQlS	PQlS_P	PQlS_V	AFD	AFN	ASA	ANS	
IVT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I-VVT	96.2551	29.8609	38.8550	50.2261	0.4060	3.5792	15.9519	0.1925	54	12.1298	38	N/A
User	86.2991	80.8015	0.0641	0	0.4989	N/A	N/A	0.4802	65	12.7843	28	N/A

IVVT





K-Means

Number of Fixation points :33225
Number of Saccade points :1346
Number of Pursuit points :5
Number of Noise points :661

Performance:

- A few high acceleration points push the remaining points into all being fixations.
- Assigning too many points as Noise affects the clusters by introducing 0-values points.
- Fixation and Pursuit merge together more than is desirable.
- Non-determinism sometimes substantially degrades the performance of K-Means.

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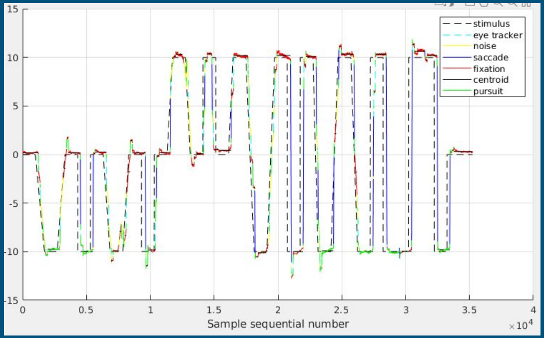

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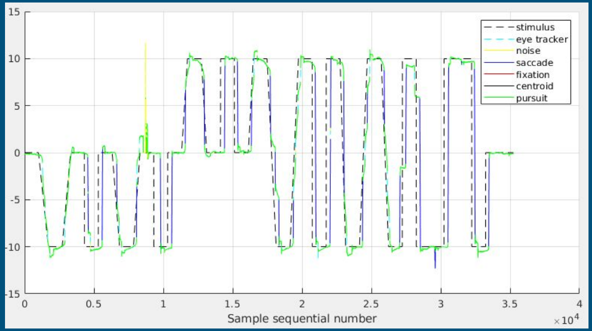
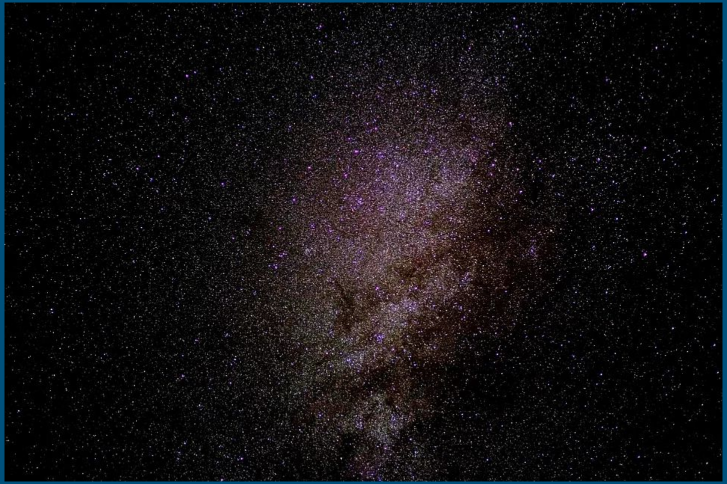


Future Improvements:

- Consider other clustering algorithms (K-Means++, C-Means, K-Medoids).
- Improve de-noising.
- Add features other than velocity and acceleration.



Questions or Comments?