A Modified K-means Algorithm for Noise Reduction in Optical Motion Capture Data

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Abstract

This paper presents a modified K-means algorithm that can be used for removing noise in multicolor motion capture image sequences. These images have been produced using the Illuminated Line Segment based Marker System described in [1]. The proposed algorithm takes into account the nature of the motion capture images in terms of the number of data pixels normally clustered together and the acceptable degree of compactness of a data cluster. The cleaned data can be used for accurate and effective tracking of the captured motion.

1. Introduction

The multicolor Illuminated Line Segment based Marker System proposed in [1] and four CCD cameras are used to capture motions from an articulated human body. The 2D multicolor images captured using the cameras are to be used to reconstruct the real-motions in virtual 3D models. This is not a straightforward process since the resulting sequences of images have high dimensionality in terms of their number of colors and a high level of embedded noise, as a result of the continuous fluctuations of light and interference of background objects.

The high dimensionality problem is to be solved by performing an initial dimensionality reduction, so that the number of distinct colors captured matches the number of colors in the Illuminated Line Segment based Markers plus background. The embedded noise is to be filtered out using a modified K-means algorithm.

Section 2 explains the nature of the motion capture images used in experiments on data pre-processing and the modified K-means algorithm. Section 3 outlines the results of noise filtering experiments. Section 4 presents the conclusion drawn from the experiments and Section 5 outlines the plan for future work in light of the lessons learned there from.

2. Experimental design

In this section, the nature of the motion capture data, pre-processing and the modified K-means algorithm used for noise filtering is described.

2. 1 The motion capture images

The images used in these experiments have been produced using the multicolor Illuminated Line Segment based Marker System proposed in [1] and synthetic ball markers. Four different cameras have been used to capture the images, all of which have an identical size of 720 x 576 pixels. Color distortions during image capture have introduced more colors in the images than those used in the original multicolor Illuminated Line Segment based Marker System. This problem has been solved by flattening each image into six regions: blue, red, purple, orange, yellow and background. The task of the modified K-means algorithm discussed in the next sub-section is to remove the noise embedded in the color regions in the images.

2. 2 The modified K-means algorithm

The modified K-means algorithm is used to clean up the noise embedded in the color regions in each image by creating clusters of pixels based on their relative spatial positions in the image. Following the classical K-means algorithm, the Euclidean Distance measure shown in Equation (1) is used to determine which cluster a pixel belongs to. Each pixel is put into a cluster, which yields the minimum Euclidean Distance between the pixel and the respective centroid. The centroid of each cluster is changed iteratively by calculating its new coordinate as the average of the sum of the coordinates of the pixels in the cluster until it converges to a stable coordinate with a stable set of member pixels in the cluster. In each iteration, the memberships of each cluster keep changing depending on the result of the Euclidean Distance calculation of each pixel against the new centroid coordinates.

$$d_{iC} = \sqrt{(x_i - x_C)^2 + (y_i - y_C)^2} \qquad \textbf{(1)}$$

where:

d_{iC} : the Euclidean distance between pixel i and a centroid C

x_i, y_i : the 2D coordinate of pixel i

x_C, y_C : the 2D coordinate of centroid C

The modifications to the classical K-means algorithm proposed in this paper (outlined in Figure 1) lie in the definition of a data vis-à-vis noise cluster and the automation of the determination of the optimum number of clusters an image should have. A cluster is considered noise if it only has a few pixels in it. The minimum number of pixels in a cluster, or the cluster size, should be set such that it minimizes the degree of false positives (i.e. data clusters incorrectly classified as noise) and false negatives (i.e. noise clusters incorrectly classified as data). The minimum cluster size is domain specific and is determined by observing the number of data points usually found in a noise cluster for the type of data at hand. In this experiment, the minimum number of pixels in a cluster is set to 8 after a few trial and error processes.

The degree of compactness of a cluster is used to determine the optimum number of clusters for a given image. In this paper, the degree of compactness of a cluster is defined as the number of pixels occupying the region of a rectangle formed by the pixels located at the outer most positions of the cluster (i.e. the pixels that have the maximum and minimum X and Y coordinates respectively). A cluster that has a lower degree of compactness than the specified value will be split further. In this experiment, the degree of compactness used is 20% which is a value just below the minimum compactness of valid data clusters for the domain observed.

K-means performs local search using randomly generated initial centroid positions. It is a known problem that the determination of the initial centroid positions plays a big part in the resulting clusters and their compositions [2], [3], [4], [5], [6], [7]. To make the search mechanism a bit more exhaustive, the modified K-means algorithm performs ten clustering exercises, using ten different initial centroid positions for each image. The result of the run that produces clusters with the maximum total degree of compactness is selected as output. Both raw and cleaned images are then plot for visualization in order to allow for easy inspections of results and to simplify verification of the outcome.

```
Procedure Modified K-Means For Noise Filtering in
Motion Capture Data
    Set minimum number of data points per cluster //
    cluster size constraint
    Set minimum cluster compactness // cluster
    compactness constraint

    For a set number of experiments do
        Set initial cluster centroids

        Set interationFlag to yes
        While iterationFlag = yes do
            Set iterationFlag to no

            // Basic K-means
            Repeat
               Calculate the distance between data
               points and each cluster centroids
               Assign each data point to cluster
               Calculate the new cluster centroids
            Until all clusters have converged

            // Filter clusters based on minimum
            cluster size constraint
            For each cluster
               If cluster has too few data points then
                  Delete cluster
               End if
            End For

            // Filter clusters based on cluster
            compactness constraint
                For each cluster

               // Find corners of compactness
               window
               Find data points with minimum and
               maximum X values
               Find data points with minimum and
               maximum Y values
               Define cluster compactness window
               size

               Calculate the number of data points
               in cluster
               Calculate cluster compactness =
               number of data points / compactness
               window size

               If cluster compactness < minimum
               compactness then
                  Split cluster into two
                  Set iterationFlag to yes
               Else
                  Record cluster compactness
```

```
                  Remove cluster and content from
          analysis
                 End if
              End For

              If iterationFlag = no then
                 Calculate the average compactness
                 of all clusters in the experiment
              End if
          End while
      End For
      Select set of clusters from experiment with the
      highest average compactness
End Procedure
```

Figure 1. Modified K-means algorithm for noise reduction in optical motion capture data.

3. Experiment results

Two types of experiments have been performed on the modified K-means. The first type focuses on filtering out spike noise, while the second tests the algorithm's ability to remove Gaussian noise with different blur radii.

3. 1 Removal of Spike Noise

The image cleaned in the first experiment is displayed in the top section of Figure 2. Here, a flattened image with multicolor Illuminated Line Segment based Markers and noise in the form of spurious black pixels can be observed. The noise data points are circled for the purpose of clarity. In the bottom section of Figure 2, the same image is shown after the modified K-means algorithm has cleaned the data.

Further experiments on synthetic data from a standard ping-pong ball style marker show that the modified K-means algorithm also is capable of cleaning this data successfully. An illustration of one result is given in Figure 3.

3. 2 Removal of Gaussian Noise

In these experiments, Gaussian blur noise with varying radii is introduced to the data points in the same data image shown in Fig 2. This causes the image to bleed out into the blur noise. The modified K-means algorithm is then used to remove this noise and recapture the data. The results of the experiments show that the Gaussian noise is completely removed regardless of the radius. In Figure 4 one can observe how much data that can be recaptured after Gaussian noise is removed. It shows that the number of data points recaptured naturally decreases as the radius of the Gaussian noise increases. However, it is also shown that the degradation of performance occurs gradually, as oppose to abruptly, when the radius is increased up to 2.5 pixel.

For this reason, it can be concluded that the modified K-means is capable of removing Gaussian noise while keeping false positives to the minimum. This result is better than the performance of the mean and median filters that are well known to only suppress (i.e. reduce) Gaussian noise rather than remove it [8].

3. 3 Processing

The processing time was found to increase with each additional cluster centroid needed in order to analyze a dataset. Experiments show that if the level of noise is at 16% and above (this number is dependent on the color composition of the noise at hand and the threshold values set for each marker component in pre-segmentation), the calculation time becomes so great (when using one Pentium 4 processor) that noise cleaning becomes impractical. This problem can be dealt with in three ways. The first is to ensure that capturing sensors and tools used for data transfer support lowest possible interference of noise. The second method, which only partially solves the problem, is to increase the value for the minimum number of data points per cluster constraint, such that more noisy data points can be removed from the dataset using a smaller number of cluster centroids. Here, it is important to notice that when the constraint value becomes greater than the number of data points usually clustered together in valid data, the number of false positives will increase. The third method for solving the problem would be to increase processing power.

4. Conclusions

This paper presents a modified K-means algorithm used to remove noise from motion capture images with the Illuminated Line Segment based Markers presented in [1].

The modifications to the classical K-means algorithm are in the form of constraints on cluster size and cluster compactness. The value for the cluster size constraint is set just above the number of data points usually found in a noise cluster for the type of data at hand. The value for the cluster compactness constraint is set just below the minimum compactness of valid data clusters.

The experiment shows that:

- Flattening line segments in the image into five color regions and background in data pre-processing helps in the reducing the number of dimensions the algorithm must cluster.
- The modified K-means algorithm manage to clean spike noise in motion capture images with both Illuminated Line Segment based Markers and classical ping-pong ball style markers.
- The modified K-means algorithm manage to completely remove Gaussian blur noise with varying radii, with a gradual increase of false positives as the blur radius increases. This is a better result than that produced by traditional median and mean filters.

5. Future work

Currently, research into suitable algorithms for automating marker midpoint estimation has been initiated.

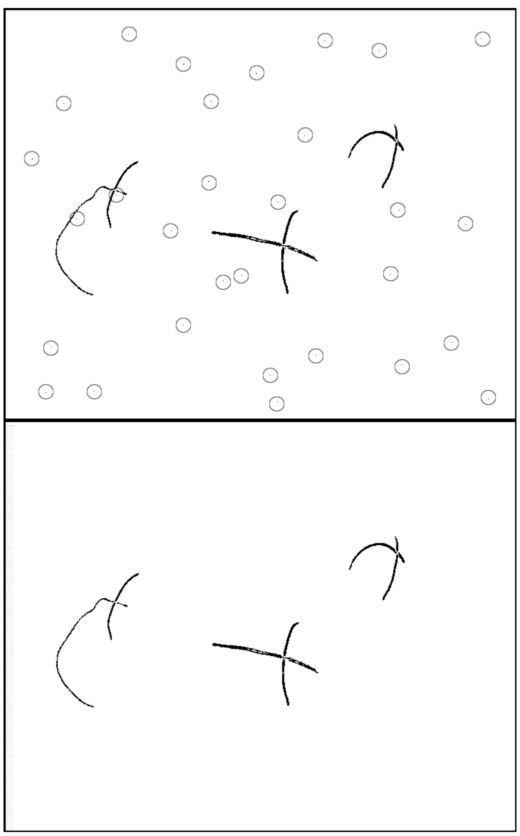

Fig 2. Top: A raw motion capture image with illuminated line segment based markers and noise (encircled). Bottom: The resulting flatten image with noise removed.

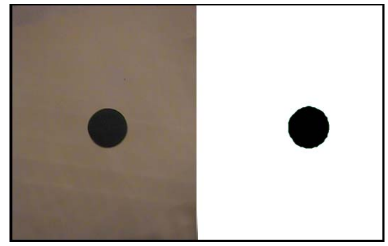

Fig 3. Left: A raw image generated from a synthetic black ball marker. Right: The image with noised removed.

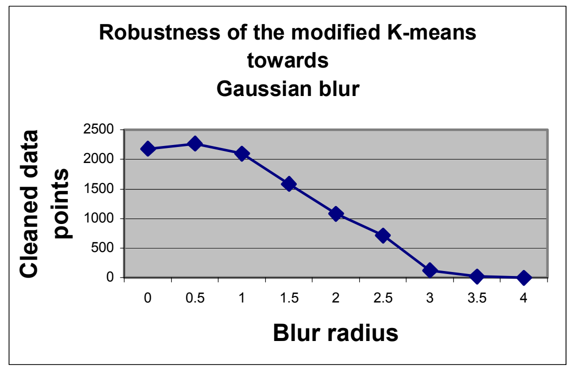

Fig 4. Number of cleaned data points after the removal of the Gaussian blur noise with varying radii using K-means (number of cleaned data points is displayed vertically, while Gaussian blur pixel radius horizontally.

When the appropriate algorithm has been implemented, future research will involve investigating a color calibration method, which aims to synchronize the input from capturing cameras, in order to allow more markers with distinctive color combinations to be generated. After this, research will focus on tracking marker midpoints over time.

6. References

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